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## THE IDENTITY OF ASCHARITE, CAMSELLITE, AND $\beta$ -ASCHARITE WITH SZAIBELYITE; AND SOME RELATIONS OF THE MAGNESIUM BORATE MINERALS\*

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### ABSTRACT

The published values of the indices of refraction of ascharite,  $2\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$ , are shown to be incorrect. The correct values, with new chemical analyses, and x-ray powder photographs, show the identity of szaibelyite, ascharite, camsellite, and  $\beta$ -ascharite. A compilation and discussion of the properties and analyses of these minerals is presented.

The isomorphous series szaibelyite-sussexite is discussed with a compilation of properties and analyses, and the variation curve plotted. A similar treatment is given for the fluoborites. The indices of refraction for the magnesium borate minerals with corrections are compiled.

### INTRODUCTION

The only recorded determinations of the indices of refraction of ascharite,<sup>1</sup> a hydrous borate of magnesium,  $2\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$ , from the German potash deposits near Stassfurt, are those given by Larsen<sup>2</sup> on material from Schmidtmanshall, near Aschersleben, namely  $\alpha = 1.53$ ,  $\beta$  and  $\gamma = 1.55$ , somewhat variable, negative with small  $2V$ , and the single value of 1.54 for the mean index given by Boeke<sup>3</sup> on ascharite from Neustassfurt.

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<sup>1</sup> Named after Ascharia, an old Latin province. The present locality name is Aschersleben in the province of Saxony, southern Prussia.

<sup>2</sup> Larsen, E. S., *The Microscopic Determination of the Nonopaque Minerals: U. S. Geol. Survey, Bull.* **679**, 42 (1921).

<sup>3</sup> Boeke, H. E., *Ueber die Borate der Kalisalzlagernstätten: Centralbl. Mineral., Geol., Pal.*, 535 (1910).

These consistent values differ considerably from those determined for other named minerals (szaibelyite, camsellite, and  $\beta$ -ascharite) of very similar, if not identical composition, and considerable confusion has resulted in the systematic placing of ascharite and in its relation to these other minerals. It will be shown that the values given by Larsen and Boeke are not the correct indices of refraction of ascharite, that its correct indices are the same as those of the other named minerals, and that all are identical.

#### PROPERTIES OF ASCHARITE

The obvious procedure to try to reconcile these inconsistencies was to restudy the specimen on which Larsen made his optical determinations. This specimen, formerly in the collection of Col. W. A. Roebling, is now in the U. S. National Museum, and through the courtesy of Dr. W. F. Foshag, it was obtained for such restudy.

The specimen (U. S. Nat. Mus. Cat. No. R 5846) is a small massive piece weighing about 40 grams, of a dull white chalky appearance, and was purchased by Colonel Roebling from Schuchardt in 1890. The label gives the locality as Schmidmannschacht near Aschersleben, Prussia.

A thin section ground in alcohol showed the material to be very finely fibrous in structure with an apparent low birefringence, and homogeneous except for discrete particles of minute size irregularly disseminated. When crushed fragments were examined in immersion oils, the indices of refraction seemed to be close to the values given by Larsen and by Boeke. The writer obtained 1.54 to 1.55, variable, and Miss J. J. Glass found 1.55 to 1.56, variable. Neither result was satisfactory and accurate consistent values could not be obtained.

These determined values, consistently about 1.55 and obtained by four different individuals, lie within the range of the indices of other magnesium borates such as kaliborite (1.51–1.55), sulphoborite (1.53–1.54), lueneburgite (1.52–1.55), and fluoborite (1.52–1.57), and suggested that Colonel Roebling's specimen might be one of these. Tests showed the absence of  $P_2O_5$  and of F but the presence of both potash and sulphate. Hence it seemed necessary to make a complete analysis of the material in order to determine its identity. Accordingly, about eight grams of selected material were crushed to 100 mesh size, the powder offering no difficulty in sieving, and the sample then analyzed.

The first results obtained were very confusing. The loss on ignition was about 20 per cent (ascharite yields 11 to 12 per cent loss), indicating possibly kaliborite or sulphoborite but determinations of  $K_2O$  and of  $SO_3$  gave results of less than one per cent each. The material gave a good yellow color to the blowpipe flame and had a bitter saline taste. Evi-



dently considerable saline material was present in the sample and a determination of material soluble in cold water yielded the unexpected high value of about 20 per cent when air dried, or about 15 per cent when dried at 110°. A ten minute water leach suffices to remove all the water-soluble material.

When the insoluble residue was examined under the microscope, its indices of refraction were seen to be much higher than previously found, with a strong birefringence. Even the minute fibers showed brilliant interference colors. Parallel to the elongation of the fibers the index of refraction was 1.58, and normal to the elongation 1.65,  $\pm 0.01$ . On account of the extreme minuteness of the interlocking fibers, the indices could not be determined more accurately. These indices are the same as those determined on the other named minerals of similar composition, as are also the chemical analyses and x-ray powder photographs. Hence the specimen is ascharite thoroughly coated and impregnated with water-soluble saline material. Consequently the indices of refraction (1.53–1.56) measured by Larsen, Boeke, Miss Glass, and the writer, on the material before water leaching represent neither the true indices of ascharite nor the indices of any single mineral, but are a meaningless composite or average value of the indices of ascharite plus those of the enclosing complex saline material.

TABLE 1. ANALYSIS OF ASCHARITE SPECIMEN IMPREGNATED  
WITH SALINE MATERIAL

	Water-soluble saline material	Water-insoluble magnesium borate	Average
Cl	5.64, 5.85	—	5.75
SO <sub>3</sub>	0.85, 0.82, 0.77	—	0.81
Mg	1.96, 1.97	—	1.97
K <sub>2</sub> O	0.46, 0.38, 0.43	—	0.42
Na <sub>2</sub> O	1.18, 1.14, 1.06	—	1.13
CaO	None	—	None
MgO	—	37.73, 37.56	37.65
B <sub>2</sub> O <sub>3</sub>	—	32.58, 32.21	32.40
Insoluble in HCl	—	0.13, 0.06, 0.08, 0.12	0.10
R <sub>2</sub> O <sub>3</sub> <sup>a</sup>	—	0.11, 0.13	0.12
Loss below 110° <sup>b</sup>	—	—	7.26
Loss above 110° <sup>b</sup>	—	—	13.30
			100.91

<sup>a</sup> Chiefly iron oxide.

<sup>b</sup> Essentially H<sub>2</sub>O but the loss above 110° may include a little Cl or chloride which may account for the high summation. Sodium tungstate used as retaining flux.

The analysis of the sample—ascharite plus saline material—is shown in Table 1. The analysis of the ascharite freed from the saline material by water leaching is shown in Table 2. The ratio of MgO to B<sub>2</sub>O<sub>3</sub> in the water insoluble portion (Table 1) is 0.934:0.465 or 2:1, the same as that in ascharite, and it is evident that the specimen is composed of about 80 per cent of ascharite impregnated with about 20 per cent of saline material. About half the powdered sample was then leached with water, thoroughly washed with cold water, then with acetone, air dried at room temperature for 48 hours, and analyzed with the results shown in Table 2.

TABLE 2. ANALYSIS OF ASCHARITE FREED FROM SALINE MATERIAL BY LEACHING WITH WATER

		Average
MgO	47.21, 47.10, 47.05, 47.13	47.12
B <sub>2</sub> O <sub>3</sub>	40.17	40.17
R <sub>2</sub> O <sub>3</sub>	0.30, 0.19, 0.39	0.29
Insoluble in HCl	0.11, 0.08, 0.12	0.10
Total H <sub>2</sub> O	12.03, 11.89, 12.07	12.00
Cl, SO <sub>3</sub> , Alk.	Traces	Traces
		99.68
The loss of water:		
At 110°	0.31, 0.37	
At 200°	0.13	0.98
At 400°	0.40	
Above 400°	11.05, 10.68	
Average loss of H <sub>2</sub> O above 400° = 10.90		

Considering only the essential constituents, namely MgO, B<sub>2</sub>O<sub>3</sub>, and H<sub>2</sub>O (ignition loss above 400°), the ratios are:

	Per cent	Molecular ratios
MgO	47.12	1.169 or 2.00
B <sub>2</sub> O <sub>3</sub>	40.17	0.577 or 0.99
H <sub>2</sub> O	10.90	0.606 or 1.04

These ratios yield the formula 2MgO·B<sub>2</sub>O<sub>3</sub>·H<sub>2</sub>O.

#### PROPERTIES AND ANALYSES OF SZAIBELYITE, ASCHARITE, CAMSELLITE, AND β-ASCHARITE

The analyses of the variously named hydrous magnesium borate minerals corresponding to the formula 2MgO·B<sub>2</sub>O<sub>3</sub>·H<sub>2</sub>O are given in Table 3, together with their indices of refraction and specific gravities.

TABLE 3. PROPERTIES AND ANALYSIS OF MINERALS (SZAIBELYITE, ASCHARITE, CAMSELLITE, AND  $\beta$ -ASCHARITE) CORRESPONDING TO THE FORMULA  $2\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$

	Szaibelyite					Ascharite					Camsellite		$\beta$ -ascharite	$2\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$
	Ne- vada	Cho- sen	Hungary		Swe- den	Germany					Can- ada	Calif.	USSR	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
$\alpha$	1.575	1.576	1.578	1.59	1.575	1.58	—	—	—	—	1.575	1.580	1.575	1.575
$\beta$	—	—	—	—	—	—	—	—	—	—	1.649	—	1.642	1.646
$\gamma$	1.650	1.650	1.651	1.65	1.650	1.65	—	—	—	—	—	—	1.651	1.646
B	.075	.074	.073	.05	.075	.07	—	—	—	—	.078	.071	.071	.075
2V	0°	—	—	—	—	Small	—	—	—	—	Small	—	28°	25°
G	2.76	—	2.7	—	—	2.69	—	—	2.7	2.7	2.60	2.6	2.65	2.65
MgO	46.72	—	52.49	49.44	—	47.12	49.2	47.1	47.0	46.9	45.24	48.84	46.70	47.91
FeO	—	—	—	—	—	—	—	—	—	—	1.28	—	0.02	—
MnO	—	—	—	—	—	—	—	—	—	—	1.09	—	—	—
CaO	1.26	—	—	—	—	—	—	—	—	—	—	—	0.00	—
B <sub>2</sub> O <sub>3</sub>	31.22	—	36.66	34.60	—	40.17	42.8	41.5	41.5	41.7	40.40	40.49	40.85	41.38
H <sub>2</sub> O +	9.87	—	6.99	12.37	—	12.00	8.0	11.4	11.3	11.2	10.55	10.67	10.95	10.71
H <sub>2</sub> O—	1.26	—	—	—	—	—	—	—	—	—	0.26	—	0.32	—
Fe <sub>2</sub> O <sub>3</sub>	4.21	—	1.66	3.20	—	0.25	—	—	—	—	0.85	—	0.13	—
Al <sub>2</sub> O <sub>3</sub>	0.63	—	—	—	—	—	—	—	—	—	0.29	—	0.16	—
SiO <sub>2</sub>	4.83	—	0.20	—	—	0.10	—	—	—	—	—	—	0.20	—
Cl	—	—	0.49	0.20	—	—	—	—	—	—	—	—	0.11	—
SO <sub>3</sub>	—	—	—	—	—	—	—	—	—	—	—	—	0.69	—
Alk.	—	—	—	—	—	—	—	—	—	—	0.04	—	0.46	—
	100.00	—	98.49	99.81	—	99.63	100.0	100.0	99.8	99.8	100.00	100.00	100.59	100.00

#### References:

- Gillson, J. L., and Shannon, E. V., Szaibelyite from Lincoln County, Nevada: *Am. Mineral.*, **10**, 137-139 (1925).
- Watanabe, Takeo, Kotoite, ein neues gesteinsbildendes Magnesium-borat: *Mineral. u. Petrogr. Mitteil.*, **50**, 448 (1939).
- Peters, K. F., A. Stromeyer's Analysis des Minerals Szeibelyit: *Sitz. K. Akad. Wissensch. Wien*, **47** (1), 347-354 (1863). Needles. Sample contained much kotoite, the anhydrous magnesium borate, thus accounting for the low percentage of water. See Watanabe (ref. 2), p. 454. Indices of refraction by Watanabe (p. 452).
- Peters, same reference as no. 3. Large grains. Indices of refraction by Loew. *Abst. in Zeits. Krist.*, **54**, 180-181 (1914). Slavik gave  $\epsilon(\alpha)=1.575$ ,  $\omega(\gamma)=1.60$ , a low value. See *Am. Mineral.*, **13**, 230 (1928), for references.
- Geijer, Per, The paragenesis of ludwigite in Swedish iron ores: *Geol. Fören. Stockholm Förh.*, **61**, 27 (1939).
- Present paper. Specific gravity (G) by Boeke, H. E., Ueber die Borate der Kalisalz-lagerstätten: *Centralbl. Mineral., Geol., Pal.*, 535 (1910).
- Feit, W., Ueber Ascharit, ein neues Borsäuremineral: *Chemikerzeitung*, **15**, 327 (1891). From Schmidtmannshall near Aschersleben. Average of three analyses.
- van't Hoff, J. H., *Untersuch. ozean. Salzablagerungen*: 347 (1912).
- Same reference as 7. From Neu-Stassfurt.



10. Same reference as 7. From Schmidtmannshall.

11. Ellsworth, H. V., and Poitevin, Eugene, Camsellite, a new borate mineral from British Columbia, Canada: *Trans. Roy. Soc. Canada*, Sect. IV, Ser. 111, **15**, 1-8 (1921). Recalculated analysis with admixed dolomite and serpentine deducted. The  $\beta$  index given in Table 3 is the  $\gamma$  value of Ellsworth and Poitevin.

12. Eakle, A. S., Camsellite from California: *Am. Mineral.*, **10**, 100-102 (1925). Eakle's  $\gamma$  is probably  $\beta$ . Analysis given with serpentine deducted. See following paragraphs.

13. Godlevsky, M. N., Mineralogical investigation of the Inder borate deposits: *Mém. Soc. Russe Mineral.*, ser. 2, **66**, 315-344 (Russian), 345-368 (English), 1937. Abstr. in *Min. Abstr.*, **7**, 122-123 (1938). 2V from indices. Boky, G. B., Kristallographische Untersuchung der Borate des Indersky-Fundortes: *Bull. Acad. Sci. URSS*, 1937, 871-881 (Russian), 882-883 (German) gives  $\alpha = 1.576$ ,  $\beta$  near  $\gamma$ ,  $\gamma = 1.646$ , biaxial, negative.

14. Calculated composition and average indices of refraction for  $2\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$ .

A comparison of the figures given in Table 3 leaves little doubt as to the identity of all these minerals. The only discordant value reported in the literature is the large axial angle (about  $80^\circ$ ) inferred by Winchell<sup>4</sup> for camsellite from Canada. Gillson and Shannon described the szaibelyite from Nevada as being uniaxial, as does Loew for the mineral from Hungary, although it is listed as being "Optically biaxial" by Dana. Larsen describes the ascharite from Germany as "with small 2V."

Ellsworth and Poitevin,<sup>5</sup> in the description of the optical properties of camsellite state: "The fibres of camsellite are always flattened parallel to the axial plane. The extinction is parallel and suggests that the mineral is orthorhombic. Its elongation is negative while that of the admixed chrysotile is positive. The habit of the mineral does not allow the emergence of an optic axis and for that reason  $\beta$  could not be determined. No attempt was made to measure 2V but this angle is probably very large.  $\alpha$  and  $\gamma$  were determined by the oil immersion method." The indices of refraction are given as  $\alpha = 1.575$  and  $\gamma = 1.649$ ,  $\pm 0.005$ . No reason is given for the statement that 2V "is probably very large." It is possible that they observed the emergence of the very large obtuse bisectrix on the broad face of the laths.

The writer<sup>6</sup> had previously noted the probable identity of camsellite with szaibelyite. This conclusion was questioned by Winchell<sup>7</sup> as in the original description of camsellite it was stated that the axial angle is probably very large, whereas that of szaibelyite is zero or very small. Winchell states that by turning a capillary glass tube containing a lath-shaped crystal of camsellite,  $\beta$  was measured as  $1.620 \pm .005$ . "Assuming no error in this determination of  $N_m$ , the optic angle (2V) must be nearly

<sup>4</sup> Winchell, A. N., Camsellite and szaibelyite: *Am. Mineral.*, **14**, 49 (1929).

<sup>5</sup> Ellsworth and Poitevin, *op. cit.*, p. 7.

<sup>6</sup> Schaller, W. T., The probable identity of camsellite with szaibelyite: *Am. Mineral.*, **13**, 230-232 (1928).

<sup>7</sup> Winchell, A. N., Camsellite and szaibelyite: *Am. Mineral.*, **14**, 48-49 (1929).

80°," using the values of  $\alpha=1.575$  and  $\gamma=1.649$  given by Ellsworth and Poitevin, and assuming that the axial plane is parallel to the broad lath face with  $Y$  normal to the laths. Winchell concludes: "Therefore the two minerals cannot be the same even if there is no chemical difference between them, a condition which is not yet fully proved."

It seems to the writer that direct observation of the optical interference figure with determined optical orientation on camsellite would yield more decisive conclusions than any indirect method, the results of which even Winchell does not seem sure of, as he qualifies his conclusion with the statement: "Assuming no error in this determination." Such direct observations, described in the following paragraphs, do not bear out his statement that the "optic angle ( $2V$ ) must be nearly 80°," in fact, they show that the axial angle of camsellite is small, less than 30°, probably somewhere in the range of 0° to 25°, and hence in accord with the data given for *szaibelyite*, *ascharite*, and  $\beta$ -*ascharite*.

Microscopic examination of a sample of camsellite from Canada (U. S. Nat. Mus. Coll. No. 95584) shows that the mineral forms exceedingly thin laths or flattened fibers, a habit incompatible with any uniaxial mineral; hence camsellite must be biaxial. These laths are so minute that ordinary observation under the microscope with a no. 7 objective fails to reveal the true optical orientation. The laths give the impression of being parallel to the optic axial plane as no interference figure can be seen under ordinary conditions. However, with an optical system especially arranged for the study of minute crystal grains, the true optical orientation can be determined directly, and it is found that  $Z$ , the obtuse bisectrix, and not  $Y$ , is normal to the broad lath faces, and hence the axial plane is normal to and not parallel to the broad lath faces.  $X$  is parallel to the elongation as in all these borates.

The special optical arrangements were suggested and carried out by Dr. Clarence S. Ross, who has had extensive experience in determining the optical orientation of minute fragments and who has arranged a microscope system especially adapted for the study of the optical properties of unusually minute grains. The specially arranged microscopic adaptations were, essentially, very intense illumination, a condensing system with a numerical aperture of 1.40, oil immersion objective, and the sliding stop eyepiece.

An aggregate of camsellite fibers was dispersed in water by means of a small mechanical stirrer and then thoroughly washed with acetone. Bakelite was then added, a little acetone being allowed to remain on the dispersed camsellite to prevent aggregation of the mineral laths and to act as a thinner. A thin smear of the bakelite plus camsellite was then applied to a glass slide, allowed to stand for a few hours for the acetone to evapo-



rate and then cured overnight at a temperature of 80° C. By this means laths of camsellite with a minimum of distortion were fixed in a variety of positions in a rigid medium of suitable index of refraction.

No essential water is lost by any of these magnesium borates or by sussexite at low temperatures, as the following recorded results show.

LOSS OF WATER AT RELATIVELY LOW TEMPERATURES

	Szaibelyite	Ascharite	Camsellite	$\beta$ -ascharite	Sussexite
110°	1.26	0.34	0.52	0.32	0.34
140°	—	—	0.02	—	—
180°	—	—	0.07	—	—
200°	—	0.13	—	—	—
250°	—	—	—	—	0.56
300°	—	—	0.08	—	—
350°	—	—	0.15	—	—
400°	—	0.40	0.12	—	—
450°	—	—	0.05	—	—
500°	—	—	0.43	—	—

Hence, curing the bakelite in which the camsellite was embedded, at 80°, cannot have had any effect on the composition of the mineral. The water content of all these borates is high-temperature water only.

Flat laths of camsellite lying parallel to the surface of the glass slide were first examined and many of these showed the emergence of a centered obtuse bisectrix with the axial plane parallel to the elongation of the laths. On turning the stage of the microscope the isogyres pass very far outside the field, although the optical system of the microscope is such that for a mineral with  $2V$  of 90° or 100°, the isogyres would be only slightly outside of the field. Thus it is evident that the obtuse axial angle in camsellite is extremely large, being much closer to 180° than to 90°, and consequently the acute angle must be small.

The acute bisectrix is parallel to the direction of elongation of the laths and hence would be observable if the laths stand on end. It was not possible to see any laths in this position but those inclined downward at a high angle showed an off-center interference figure adequate for study. A number of laths were seen lying in such an inclined position that the acute bisectrix emerged outside of, but very close to the border of the field.

On rotation of the stage, the visible isogyre for some laths moved across the field of view with seemingly complete parallelism, in other laths a slight curvature was observable in the 45° position. This shows that the axial angle of camsellite is small, not exceeding about 30°, with possibly some variation due to slight distortion of the laths. The optical



character of the acute bisectrix figure is negative, and the slight dispersion is  $r > v$ .

The distinction between camsellite and the admixed or associated chrysotile is obvious, but for every lath of camsellite on which optical determinations were made, its identity was checked by comparison of its indices of refraction against the enclosing bakelite (determined  $n = 1.627$ ),  $\beta$  of the camsellite being a little higher (estimated 0.02 higher) and  $\alpha$  being considerably lower.

Hence camsellite is definitely biaxial with a small optic angle which is estimated to be not far from  $25^\circ$ , and may be considerably smaller. The value  $1.649 \pm 0.005$ , given by Ellsworth and Poitevin for  $\gamma$ , in reality is  $\beta$ , and  $\gamma$  must be slightly higher. These results agree with those given for  $\beta$ -ascharite, whose identity with camsellite has been shown by x-ray powder photographs by Agafonova and Isküll,<sup>8</sup> and which Godlevsky describes as forming "separate plates" as well as fibers. His figure 18, a photomicrograph of  $\beta$ -ascharite, would pass just as readily for a photomicrograph of camsellite. Sussexite, the manganese analogue of szaibelyite, also occurs as laths, rather than fibers. Slawson states: "The fibers are flattened so that most of them yield  $\alpha$  and  $\beta$ ," as do the laths of camsellite.

Camsellite,	$\beta$ -ascharite,
$\alpha = 1.575$ ,	1.575 <sup>a</sup> 1.576 <sup>b</sup>
$\beta = 1.649$	1.642
	} 1.646
$\gamma = \text{---}$	1.646
$2V \ 20^\circ\text{--}30^\circ$	$28^\circ$

<sup>a</sup> Godlevsky

<sup>b</sup> Boky

The values listed for  $\gamma$  in Table 3 for the various samples of szaibelyite from different localities may be either  $\beta$  or  $\gamma$ , or an intermediate value. The true value for  $\gamma$  may be slightly greater than 1.650, but the actual difference between  $\beta$  and  $\gamma$  is very small and comparable in magnitude with the errors of measurement on such fibrous material.

If it be assumed that for camsellite  $\alpha = 1.575$  and  $\beta$  (usually given as  $\gamma$ ) = 1.649, then with an assumed  $2V$  of  $25^\circ$ ,  $\gamma$  would become about 1.653. There is no conclusive evidence that there is a marked difference in  $2V$  for the two end members of the szaibelyite-sussexite series. Sussexite no. 9 (Table 5) gives  $\gamma - \beta = 0.008$ , yielding a  $2V$  angle of  $37^\circ$  but sussexite no. 8 has  $\gamma - \beta$  only 0.003, and sussexite no. 10 has  $\gamma - \beta$  not greater than 0.005.

<sup>8</sup> Agafonova, T. N., and Isküll, E. W., Identity of the Inder ascharite and camsellite: *C. R., Acad. Sci., URSS*, **22**, 325-326 (1939).

Evidently, the mineral szaibelyite (= ascharite, camsellite,  $\beta$ -ascharite) is orthorhombic, biaxial, with a small axial angle which has been taken by some observers to be uniaxial. It is possible that some varieties are almost uniaxial as it is common for nearly uniaxial minerals to show a slight variation in the size of the optic angle.

As the name szaibelyite has priority, the names ascharite, camsellite, and  $\beta$ -ascharite are to be discarded as needless synonyms. The ascharite from Germany should not be referred to as  $\alpha$ -ascharite, in distinction to  $\beta$ -ascharite, as suggested by the describers of  $\beta$ -ascharite, based on the incorrect assumption that the indices of refraction of the ascharite from USSR were different from those of ascharite from Germany. The name magnesiosussexite also should be discarded as the mineral is a manganoan szaibelyite.

Eakle considered the silica present in the analysis of camsellite from California as an essential constituent. "It is not a case of admixed silica or silicate, but rather a definite replacement of one molecule of  $B_2O_3$ , by  $SiO_2$  . . ." He also stated: "No dolomite or chrysotile occurs with it and by lightly scraping the coatings pure material was obtained." Regarding its insolubility in acid he said: "The silica may act like an opal in the fibers preventing them from ready attack by the acid and dehydration changes this condition of the silica."

The ratios of Eakle's analysis give:  $(Mg,Fe)O:B_2O_3+SiO_2:H_2O = 1.98:1.00:1.02$ , apparently supporting his claim that the silica is an inherent constituent of the camsellite. However, as his indices of refraction and specific gravity are practically identical with those for other occurrences of the mineral, it is believed that his conclusion is not correct. If seven per cent of  $SiO_2$  actually replaced the equivalent quantity of  $B_2O_3$ , the replacement should be reflected in a material change in the indices of refraction.

A microscopic examination of a specimen of camsellite, from near Stinson Beach, Marin County, California (U. S. Nat. Museum Coll. no. 95183), indicates that it would be impossible to prepare a sample of this borate mineral free from serpentine. While it is true as Eakle states that "No dolomite or chrysotile occurs with it," careful examination shows that minute particles of massive serpentine (not chrysotile as in the camsellite from Canada) are scattered throughout the fibers of the borate mineral and the  $SiO_2$  reported in Eakle's analysis probably represents admixed serpentine.

Twelve samples from different parts of the specimen were removed, and after picking out the visible fragments of serpentine were examined in immersion oils of the proper index. By spreading out the preparation into a very thin layer under the cover glass and using high magnification



(Leitz objective no. 7), abundant fragments of serpentine (massive, very low birefringence, mean index about 1.55) can be seen. Some of the serpentine is nearly colorless, other fragments are pale yellow, and still others are dark olive colored. Minute black specks are also present. In some pieces, the camsellite is replacing the serpentine and where abundantly developed, an apparent solid group of fibers of camsellite can be seen largely replacing but still retaining much of the serpentine as a matrix for the fibers which then cannot be broken down into single loose fibers.

Ascribing the  $\text{SiO}_2$  in Eakle's analysis to serpentine and deducting it (with the corresponding amounts of  $\text{MgO}$  and  $\text{H}_2\text{O}$ , as required by the formula  $3\text{MgO} \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$ ) from the molecular ratios of the analysis, the remaining ratios come out very close to 2:1:1, as required by the formula  $2\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$ , as shown in Table 4.

TABLE 4. RATIOS OF EAKLE'S ANALYSIS OF CAMSELLITE FROM CALIFORNIA, DEDUCTING  $\text{SiO}_2$  AND CORRESPONDING AMOUNTS OF  $\text{MgO}$  AND  $\text{H}_2\text{O}$ , AS SERPENTINE

Ratios of Eakle's analysis		Ratios of serpentine	Ratios of silica-free borate
$\text{MgO} + \text{FeO}$	1.1768	.1788	.9980 or 2.03
$\text{B}_2\text{O}_3$	.4787	—	.4787 or 0.97
$\text{SiO}_2$	.1192	.1192	— —
$\text{H}_2\text{O}$	.6072	.1192	.4880 or 0.99

Treatment of the sample with cold 1:1  $\text{HCl}$  readily yields a yellowish solution, and probably most of the iron in the sample is in the serpentine rather than in the camsellite. If all the  $\text{FeO}$  in the analysis is assigned to the included serpentine, Eakle's analysis may be recalculated as follows:

TABLE 5. RECALCULATION OF EAKLE'S ANALYSIS, DEDUCTING SERPENTINE,  $3(\text{Mg}, \text{Fe})\text{O} \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$

Analysis		Admixed serpentine		Remaining camsellite		$2\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$
		$3\text{MgO} \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$	$3\text{FeO} \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$			
$\text{MgO}$	46.07	5.85	—	40.22	48.84	47.91
$\text{FeO}$	2.46	—	2.46	—	—	—
$\text{B}_2\text{O}_3$	33.34	—	—	33.34	40.49	41.38
$\text{SiO}_2$	7.16	5.80	1.36	—	—	—
$\text{H}_2\text{O}$	10.94	1.74	0.41	8.79	10.67	10.71
	99.97	13.39	4.23	82.35	100.00	100.00

These values for the serpentine-free camsellite are much closer to those required by the formula  $2\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$ , than those previously calculated by the writer<sup>9</sup> on the basis of deducting only  $\text{SiO}_2$ , and are those given in column 12 of Table 3.

The apparent discrepancy in the recorded statements as to the acid solubility of various samples of this mineral is more apparent than real. As far as available material permitted tests to be made, the mineral is soluble in cold 1:1 HCl, but only very slowly. It takes several days for it to dissolve completely in cold 1:1 HCl, but digestion on the steam bath with hot 1:1 HCl completely dissolves it in a few hours, as shown by tests made on ascharite from Germany and camsellite from Canada and from California. Both samples of camsellite yielded silica skeletons from the admixed serpentine. Eakle's statement that the camsellite from California "is so slowly attacked that boiling for hours fails to decompose it" could not be verified. However, he does not state that he tested the filtered solution for magnesium or for boric acid, and either the insoluble silica skeletons of admixed serpentine or possibly some of the remaining coarser camsellite may have led him to conclude that the mineral was insoluble.

Similar errors, resulting from not testing the filtrate for dissolved matter, have occurred before. For example J. W. Daly, in describing the sepiolite from Crestmore, California (*Am. Mineral.*, **20**, 652, 1935), states that: "It is unattacked by HCl." This statement is not correct for a sample of this mineral kindly furnished by Mr. Daly was attacked by cold 1:1 HCl after several days, the filtrate containing abundant magnesium, but the residual insoluble silica skeleton of the sepiolite *looked* exactly like the untreated sepiolite when first introduced into the acid.

#### X-RAY POWDER PHOTOGRAPHS

No single investigation on all occurrences of all these minerals has been carried out on the basis of x-ray photographs. However, such pictures have been made on small groups of all these minerals.

Watanabe<sup>10</sup> reports the identity of szaibelyite from Hungary, ascharite from Leopoldshall, Germany, and camsellite from California; Dr. W. E. Richmond of the Geological Survey has compared photographs of ascharite from Aschersleben, Germany (the water-leached sample, analysis in Table 2), camsellite from Canada (U. S. Nat. Mus. Cat. No. 95584), and sussexite from New Jersey (U. S. Nat. Mus. Cat. No. C4459), and reports

<sup>9</sup> Schaller, W. T., The probable identity of camsellite with szaibelyite: *Am. Mineral.*, **13**, 232 (1928), column 6.

<sup>10</sup> Watanabe, Takeo, Kotoit, ein neues gesteinsbildendes Magnesiumborat: *Mineral. u. Pet. Mitteil.*, **50**, 454 (1939).



them identical with no difference between ascharite and camsellite and only a spacing difference for sussexite. Agafonova and Isküll<sup>11</sup> state that  $\beta$ -ascharite from the Inder region and camsellite from Canada are identical; and Gruner shows the identity of camsellite from Canada, magnesiosussexite from Michigan, and sussexite from New Jersey, with only a spacing difference.

The observed identities may be expressed schematically as follows:

TABLE 6. IDENTITY OF X-RAY POWDER PHOTOGRAPHS OF SZAIBELYITE, ASCHARITE, CAMSELLITE,  $\beta$ -ASCHARITE, AND SUSSEXITE

	Szai- belyite	Ascharite	Camsellite		$\beta$ - ascharite	Magnesio- sussexite	Sussexite
	Hungary	Germany	Canada	Calif.	USSR	Michigan	New Jersey
Watanabe	X	X	—	X	—	—	—
Richmond	—	X	X	—	—	—	X
Agafonova and Isküll	—	—	X	—	X	—	—
Gruner	—	—	X	—	—	X	X

#### GEOLOGIC OCCURRENCES OF SZAIBELYITE

Four distinct types of occurrence of szaibelyite are recorded in the literature.

(1) Contact metamorphic deposits in limestone and dolomite. Hungary, Nevada, Chosen, and Sweden.

(2) Saline deposits (ascharite and  $\beta$ -ascharite). Germany and USSR. The Inder (USSR) borates occur near the Inder salt lake, 150 km. north of the Caspian Sea in western Kazakstan, with clays and residual anhydrite in the gypsum capping of a large Lower Permian salt dome, in the underlying halite and sylvite, and in the Quaternary surface deposits (Taken from *Min. Abstr.*, **7**, 122, 1938).

(3) With serpentine (camsellite). Canada and California.

(4) A manganese-bearing variety (magnesiosussexite) in iron ore. Michigan.

#### SZAIBELYITE-SUSSEXITE SERIES

Szaibelyite,  $2\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$ , and sussexite,  $2(\text{Mn}, \text{Mg})\text{O} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$ , form an isomorphous series ranging from the manganese-free magnesium borate to a sussexite (No. 10, Table 7) of composition 80 per cent  $2\text{MnO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$  and 20 per cent  $2\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$ . The isomorphous

<sup>11</sup> Agafonova, T. N., and Isküll, E. W., Identity of the Inder ascharite and camsellite: *C. R., Acad. Sci., URSS*, **22**, 325-326 (1939).





relationship between camsellite (=szaibelyite), magnesiosussexite, and sussexite has already been shown by Gruner.<sup>12</sup> Two other isomorphous series are known among the magnesium borates, the ludwigite-vonsenite series,  $4(\text{Mg, Fe})\text{O} \cdot \text{Fe}_2\text{O}_3 \cdot \text{B}_2\text{O}_3$ , and the fluoborites  $3\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot 3\text{Mg}(\text{F, OH})_2$

The variations in the properties with changing chemical composition for the szaibelyite-sussexite series are shown in Fig. 1, the series including such minerals described under the names of szaibelyite, ascharite, camsellite,  $\beta$ -ascharite, magnesiosussexite, and sussexite. The chemical composition is expressed as weight percentage of the two end members. The plotted data are those shown in Table 7. The recorded indices of refraction of magnesiosussexite are considerably lower than they should be for a mineral of the composition given by the analysis, indicating that the material is probably variable in composition.

The calculated value of  $\beta$  for the pure magnesium component is 1.646, if the measured  $\beta$  of 1.649 ( $=\gamma$  of Ellsworth and Poitevin) is for the analyzed camsellite with 4 per cent of the manganese plus iron component.

The only example of the pure magnesium component for which all three indices of refraction were measured is the  $\beta$ -ascharite for which  $\beta$  is given as 1.642 and  $\gamma$  as 1.646. These two values are slightly lower than the other measurements.

A careful consideration of all the determined values, with allowance for the 4 per cent of the manganese and iron component in camsellite, indicates that the indices of the pure magnesium component are probably very close to  $\alpha=1.575$ ,  $\beta=1.646$ ,  $\gamma=1.650$ , with  $B=.075$  and  $2V=25^\circ$ . These are the values given in column 14 of Table 3 and in column 1 of Table 7, and are the values used in Fig. 1. The extrapolated values for the pure manganese component ( $2\text{MnO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$ ) are:  $\alpha=1.670$ ,  $\beta=1.728$ ,  $\gamma=1.732$ .  $G=3.30$ .

<sup>12</sup> Gruner, J. W., Magnesiosussexite, a new mineral from a Michigan iron mine, isomorphous with sussexite and camsellite: *Am. Mineral.*, **17**, 509-513 (1932).

TABLE 7. PROPERTIES AND ANALYSES OF MEMBERS OF THE SZAIBELYITE ( $2\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$ )-SUSSEXITE ( $2\text{MnO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$ ) SERIES

	1	2	3	4	5	6	7	8	9	10	11
Mg comp.	100	96	62	36	34	33	—	—	32	20	0
Mn comp.	0	4	38	64	66	67	—	—	68	80	100
$\alpha$	1.575	1.575	1.595	—	1.639	—	1.639	1.630	1.642	1.65	1.670
$\beta$	1.646	1.649	—	—	—	—	1.70+	1.709	1.713	1.71	1.728
$\gamma$	1.650	1.653	1.660	—	1.704	—	1.712	1.712	1.721	1.715	1.732
B	.075	.078	.065	—	.065	—	.073	.082	.079	.065	.062
2V	25°	Small	—	—	—	—	Small	22°	37°	Small	30°
G	2.65	2.60	2.83	3.42?	3.12	3.12	—	—	3.05	—	3.30
MgO	47.91	45.24	29.32	17.03	16.29	15.92	—	—	14.57	9.56	—
MnO	—	1.09	23.48	40.10	37.58	38.08	—	—	40.42	49.40	61.81
FeO	—	1.28	—	—	—	—	—	—	—	0.16	—
ZnO	—	—	0.00	—	3.87	3.24	—	—	—	—	—
CaO	—	—	0.05	—	0.10	—	—	—	0.35	2.03	—
B <sub>2</sub> O <sub>3</sub>	41.38	40.40	36.18	31.89	33.16	33.31	—	—	33.24	30.52	30.34
H <sub>2</sub> O+	10.71	10.55	10.18	9.59	7.80	9.43	—	—	8.91	8.33	7.85
H <sub>2</sub> O—	—	0.26	0.22	—	0.10	—	—	—	—	—	—
SiO <sub>2</sub>	—	—	0.43	—	0.50	—	—	—	0.89	—	—
Insol.	—	—	—	—	—	—	—	—	0.69	—	—
Fe <sub>2</sub> O <sub>3</sub>	—	0.85	1.34	—	0.60	—	—	—	0.29	—	—
Al <sub>2</sub> O <sub>3</sub>	—	0.29		—	—	—	—	—		—	—
Alk.	—	0.04	—	—	—	—	—	—	—	—	—
	100.00	100.00	100.20	98.61	100.00	99.98			99.36	100.00	100.00

## References:

1. Calculated composition of szaibelyite,  $2\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$ . Indices of refraction given are average of those given in Table 3 for szaibelyite, camsellite, and  $\beta$ -ascharite.
2. Camsellite from Canada. Ellsworth and Poitevin. The 4 per cent of the Mn component includes the analogous Fe component. The camsellite from California may contain several per cent of the analogous Fe component. Eakle reports no manganese present. The position of the camsellite from California is nearly the same as that from Canada and hence is not shown in figure 1.
3. Magnesiosussexite. Gruner, J. W., Magnesiosussexite, a new mineral from a Michigan iron mine, isomorphous with sussexite and camsellite: *Am. Mineral.*, **17**, 509-513 (1932).
4. Sussexite. Brush, G. J., On sussexite, a new borate from Mine Hill, Franklin Furnace, Sussex County, New Jersey: *Am. Jour. Sci.*, 2d ser., **46**, 240-243 (1868). Brush already noted that: "In some of its physical and chemical characters sussexite resembles the mineral szaibelyite from southern Hungary."
5. Sussexite. Poitevin, Eugene, and Ellsworth, H. V., New optical data for analyzed sussexite: *Am. Mineral.*, **9**, 188-190 (1924).
6. Sussexite. Penfield, S. L., and Sperry, E. S., Mineralogical Notes; 4. Sussexite from Mine Hill, Franklin, N. J.: *Am. Jour. Sci.*, 3d ser., **36**, 323 (1888). As in szaibelyite, only a little water is given off at low temperatures. Loss at  $100^\circ = 0.34$ , additional loss at  $250^\circ = 0.56$ .
7. Sussexite. Winchell.
8. Sussexite. Larsen. 2V calculated.
9. Sussexite. Slawson, C. B., Sussexite from Iron County, Michigan: *Am. Mineral.*, **19**, 575-578 (1934). 2V calculated.



10. Sussexite. Palache, Charles. Mineralogical Notes on Franklin and Sterling Hill, New Jersey: *Am. Mineral.*, **13**, 323 (1928).  $2V$  about  $25^\circ$ , assuming  $\beta = 1.712$ .

11. Theoretically pure sussexite,  $2\text{MnO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$ . Values for the indices of refraction and for specific gravity by extrapolation from FIG. 1. Indices probably correct within 0.005. Assuming  $\beta = 1.728$ , then  $2V$  will be about  $30^\circ$ .

### FLUOBORITE

The properties and analyses of the fluoroborites have been compiled (Table 8) in a similar manner so that the properties of the two end members,  $3\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot 3\text{MgF}_2$  and  $3\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot 3\text{Mg}(\text{OH})_2$ , may be obtained by extrapolation for inclusion in the table (Table 9) of indices of refraction of the magnesium borate minerals. The data in Table 8 are plotted in

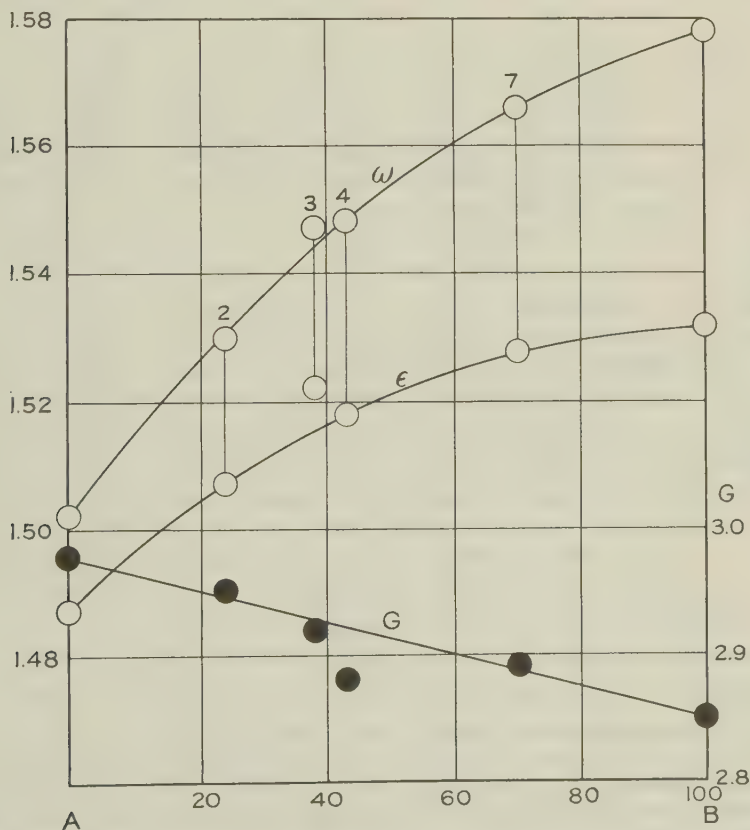


FIG. 2. Diagram showing relations between indices of refraction, specific gravity (G), and component composition (weight percentage) for the fluoroborites. A =  $3\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot 3\text{MgF}_2$  and B =  $3\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot 3\text{Mg}(\text{OH})_2$ .

Fig. 2. By plotting the birefringence against percentage composition, the fluorine end member, *A* in Fig. 2, is seen to have a birefringence of about 0.015, and the hydroxyl end member, *B* in Fig. 2, a birefringence of about 0.047. The values of the indices of refraction given in columns 1 and 8 of Table 8, for the end members, are of course only approximate.

TABLE 8. PROPERTIES AND ANALYSES OF MEMBERS OF THE FLUOBORITE SERIES

	3MgO· B <sub>2</sub> O <sub>3</sub> · 3MgF <sub>2</sub>	Malaya	New Jersey		Chosen	Nevada	Nor- berg	3MgO· B <sub>2</sub> O <sub>3</sub> · 3Mg(OH) <sub>2</sub>
	1	2	3	4	5	6	7	8
F comp.	100	76	62	57	—	—	30	0
OH comp.	0	24	38	43	—	—	70	100
$\omega$	1.502	1.530	1.547	1.548	1.550	1.561	1.566	1.579
$\epsilon$	1.487	1.507	1.522	1.518	1.522	1.527	1.528	1.532
B	.015	.023	.025	.030	.028	.034	.038	.047
G	2.98	2.95	2.92	2.88	—	—	2.89	2.85
MgO	64.07	62.02	60.07	62.07	—	—	61.65	66.17
FeO	—	1.16	—	—	—	—	—	—
MnO	—	—	1.93	2.09	—	—	0.05	—
ZnO	—	—	2.41	2.05	—	—	—	—
CaO	—	0.56	1.19	—	—	—	—	—
B <sub>2</sub> O <sub>3</sub>	18.44	17.67	17.25	18.68	—	—	17.90	19.05
F	30.20	20.94	17.60	17.14	—	—	9.30	—
H <sub>2</sub> O	—	3.23	5.22	1.29	—	—	10.78	14.78
SiO <sub>2</sub>	—	0.88	—	—	—	—	0.45	—
Al <sub>2</sub> O <sub>3</sub>	—	0.92	—	—	—	—	0.90	—
Fe <sub>2</sub> O <sub>3</sub>	—	0.36	—	—	—	—	0.81	—
CO <sub>2</sub>	—	—	1.23	—	—	—	1.36	—
O = F <sub>2</sub>	112.71	107.74	106.90	103.32	—	—	103.20	100.00
	12.71	8.82	7.41	7.22	—	—	3.92	—
	100.00	98.92	99.49	96.10	—	—	99.28	—

#### References:

1. The fluorine end member. Indices of refraction and specific gravity by extrapolation.
2. JOHNSTON, R. W., AND TILLEY, C. E., On fluoborite from Selibin, Malaya: *Geol. Mag.*, **77**, 141-144 (1940).
- 3 & 4. Palache, Charles, The minerals of Franklin and Sterling Hill, Sussex County, New Jersey: *U. S. Geol. Survey, Prof. Paper* **180**, 127-128 (1935). No. 3: "Material associated with zincite." No. 4: "Material associated with mooreite." In No. 4, the percentage of H<sub>2</sub>O is much too low, as stated. Based on the percentage of F, the percentage of H<sub>2</sub>O should be about 6.

5. Watanabe, *op. cit.*, p. 448. The indices indicate about 50 per cent of the hydroxyl end member.

6. Gilson and Shannon, *op. cit.*, p. 138. Schaller, *op. cit.*, p. 230, footnote No. 5. The indices indicate about 65 per cent of the hydroxyl end member.

7. GEIJER, PER, Some mineral associations from the Norberg district: *Sver. Geol. Unders. Årsbok*, **20** (1926), 27, 1927.

8. The hydroxyl end member. Indices of refraction and specific gravity by extrapolation.

#### INDICES OF REFRACTION OF MAGNESIUM BORATE MINERALS

In a preliminary tabulation of the optical properties of the magnesium borates, prepared originally in an attempt to place the (incorrect) published indices of ascharite, it was noted that the indices of paternoite, as given by Barth and Berman,<sup>13</sup> were almost identical with those of kaliborite. As given these are:

Paternoite,  $\alpha=1.509$ ,  $\beta=1.528$ ,  $\gamma=1.548$ , positive, monoclinic.

Kaliborite,  $\alpha=1.508$ ,  $\beta=1.526$ ,  $\gamma=1.550$ , positive, monoclinic.

At first, it was thought that this closeness in values of the indices might be accidental as the indices of sulfoborite and lueneburgite, likewise, are very similar. As however in the original description of paternoite Millosevich<sup>14</sup> gives the mean index as much lower, namely about 1.475 ( $n$  given as 1.47 to 1.48), a statement not considered by Barth and Berman, it seemed advisable to check the identity of the specimen, even though the authors state that it "ist sicherlich authentisch." Accordingly, through the courtesy of Dr. Berman, the sample (Harvard collection No. 89270) on which Barth and Berman made their determinations was loaned for restudy. A comparative qualitative test for potash made by R. K. Bailey of the Geological Survey Chemical Laboratory, indicated the presence of from 5 to 10 per cent  $K_2O$ , a quantity similar to that found for known kaliborite. Hence the supposed paternoite described by Barth and Berman is kaliborite and the optical properties given by them are to be transferred to kaliborite.<sup>15</sup>

The values given in the following table for the fluorine end member,  $3MgO \cdot B_2O_3 \cdot 3MgF_2$ , and for the hydroxyl end member,  $3MgO \cdot B_2O_3 \cdot 3Mg(OH)_2$ , of the fluoborite series,  $3MgO \cdot B_2O_3 \cdot 3Mg(F,OH)_2$ , are derived by extrapolation, as shown in Fig. 2, and are subject to correction

<sup>13</sup> Barth, Tom., and Berman, Harry, Neue optische Daten wenig bekannter Minerale: *Chemie der Erde*, **5**, 29 (1930).

<sup>14</sup> Millosevich, F., Paternoite: un nuovo minerale del giacimento salifero di Monte Sambuco in territorio di Calascibetta (Sicilia): *Rend. R. Accad. Lincei*, ser. 5, **29**, sem. 2, 286-289 (1920).

<sup>15</sup> Apparently, the small vials containing samples of supposed paternoite distributed by Palumbo (in Rome) are all kaliborite as the U. S. Nat. Museum has an identical sample, labeled paternoite, but actually kaliborite.



when more fluoborites are described. For the purpose of practical use, both values for the theoretical end members are listed in the table as well as both the lowest and the highest of the determined values for fluoborite.

Similarly, for the sussexites, the values for the pure manganese end member, derived by extrapolation as shown in Fig. 1, are listed as well as the lowest (Gruner's magnesiosussexite) and the highest values for sussexite. The magnesium end member of the sussexites is szaibelyite.

In the compilation shown in Table 9, the magnesium borate minerals are listed in the order of increasing value of  $\beta$ .

TABLE 9. INDICES OF REFRACTION OF MAGNESIUM BORATE MINERALS

		$\alpha$	$\beta$	$\gamma$	$B$	$2V$
Paternoite	$\text{MgO} \cdot 4\text{B}_2\text{O}_3 \cdot 4\text{H}_2\text{O}$	—	$n1.475$	—	—	—
Inderite	$2\text{MgO} \cdot 3\text{B}_2\text{O}_3 \cdot 15\text{H}_2\text{O}$	—	1.488	1.504	—	—, Large
Fluoborite,						
F-end member	$3\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot 3\text{MgF}_2$	$\epsilon1.487$	$\omega1.502$	$\omega1.502$	.015	—, $0^\circ$
Kurnakovite	$2\text{MgO} \cdot 3\text{B}_2\text{O}_3 \cdot 13\text{H}_2\text{O}$	1.489	1.510	1.525	.036	—, $80^\circ$
Kaliborite	$4\text{MgO} \cdot \text{K}_2\text{O} \cdot 11\text{B}_2\text{O}_3 \cdot 18\text{H}_2\text{O}$	1.508	1.526	1.550	.042	+, $81^\circ$
Fluoborite	$3\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot 3\text{Mg}(\text{F}, \text{OH})_2$	$\epsilon1.507$	$\omega1.530$	$\omega1.530$	.023	—, $0^\circ$
Hydroboracite	$\text{MgO} \cdot \text{CaO} \cdot 3\text{B}_2\text{O}_3 \cdot 6\text{H}_2\text{O}$	1.523	1.534	1.570	.047	+, $60^\circ$
Sulfoborite	$6\text{MgO} \cdot 2\text{SO}_3 \cdot 2\text{B}_2\text{O}_3 \cdot 9\text{H}_2\text{O}$	1.527	1.540	1.544	.017	—, $70^\circ$
Lueneburgite	$3\text{MgO} \cdot \text{P}_2\text{O}_5 \cdot \text{B}_2\text{O}_3 \cdot 8\text{H}_2\text{O}$	1.520	1.541	1.545	.025	—, $48^\circ$
Pinnoite	$\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$	$\omega1.565$	$\omega1.565$	$\epsilon1.575$	.010	+, $0^\circ$
Fluoborite	$3\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot 3\text{Mg}(\text{OH}, \text{F})_2$	$\epsilon1.528$	$\omega1.566$	$\omega1.566$	.038	—, $0^\circ$
Fluoborite,						
(OH)-end member	$3\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot 3\text{Mg}(\text{OH})_2$	$\epsilon1.532$	$\omega1.579$	$\omega1.579$	.047	—, $0^\circ$
Szaibelyite	$2\text{MgO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$	1.575	1.646	1.650	.075	—, $25^\circ$
Kotoite	$3\text{MgO} \cdot \text{B}_2\text{O}_3$	1.652	1.653	1.673	.021	+, $21^\circ$
Sussexite	$2(\text{Mg}, \text{Mn})\text{O} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$	1.595	—	1.660	.065	—, Small
Boracite	$5\text{MgO} \cdot \text{MgCl}_2 \cdot 7\text{B}_2\text{O}_3$	1.662	1.667	1.673	.011	+
Sussexite	$2(\text{Mn}, \text{Mg})\text{O} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$	1.65	1.71	1.715	.065	—, Small
Sussexite,						
Mn-end member	$2\text{MnO} \cdot \text{B}_2\text{O}_3 \cdot \text{H}_2\text{O}$	1.670	1.728	1.732	.062	—, $30^\circ$
Warwickite	$3(\text{Mg}, \text{Fe})\text{O} \cdot \text{TiO}_2 \cdot \text{B}_2\text{O}_3$	1.808	1.810	1.830	.022	+, $59^\circ$
Ludwigite	$4(\text{Mg}, \text{Fe})\text{O} \cdot \text{Fe}_2\text{O}_3 \cdot \text{B}_2\text{O}_3$	1.85	1.85+	2.02	.17	+, Small
Pinakiolite	$4(\text{Mg}, \text{Mn})\text{O} \cdot \text{Mn}_2\text{O}_3 \cdot \text{B}_2\text{O}_3$	1.91	2.05	2.065	.155	—, $32^\circ$
Vonsenite	$4(\text{Fe}, \text{Mg})\text{O} \cdot \text{Fe}_2\text{O}_3 \cdot \text{B}_2\text{O}_3$	—	—	—	—	—

# ORIGIN OF THE QUARTZ DEPOSIT AT FAZENDA PACÚ, BRAZIL

PAUL F. KERR<sup>1</sup> AND ALBERTO I. ERICHSEN<sup>2</sup>

## ABSTRACT

The quartz of Fazenda Pacú occurs in veins which are formed along a fracture zone at the contact between granite (Archean) and argillaceous sediment (Silurian). Rock decay has decomposed the granite and altered the binding material of the quartz of the veins. Kaolinite has resulted. Erosion has removed the upper part of some veins, redepositing the crystals in boulder beds separated by sedimentary clay. The crystal-bearing veins are probably of hypogene origin and are related to a later phase of the prominent pegmatitic invasions which have occurred in Minas Geraes.

## INTRODUCTION

Rock crystal has been mined in Brazil for many years. Early production was for ornaments or optical purposes, much of the crystal being shipped to the Orient for cutting or carving. Bauer (1904) states that 200 persons in the space of two years collected 7000 tons of material in the Serra dos Cristaes along the border of the states of Minas Geraes and Goyaz. More recently the use of quartz in radio and telephone equipment has resulted in renewed activity at many of the long known crystal producing localities. Quartz suitable for commercial use is being found in the states of Minas Geraes, Baía, Goyaz, Matto Grosso, and Amazonas, production from the first named being the most important. Various localities have been referred to in the literature in brief accounts by Leonardos and Moraes (1936), Oliveira (1938), Freyberg (1934), Walls (1929), Andrade (1941), and Wright (1941). The most productive deposit from the standpoint of large clear crystals is Fazenda Pacú, where five hundred men are employed in the diggings.

Fazenda Pacú (large ranch) lies about four hundred and fifty miles north of Rio de Janeiro in the central part of the state of Minas Geraes (Fig. 1). It is twenty-five miles from Sete Lagôas, the nearest railroad station, and eighty-five miles northwest of Belo Horizonte, the capital and principal city of the state.

Quartz has been known to occur here for a long time, but it has been only in the last few years that exploitation on a considerable scale has been attempted. The pits occur in five localities over a stretch of about seven miles, extending along a northwest-southeast line with the ranch house of Fazenda Pacú a mile and one-half from the southern end. The names of the mine workings (Fig. 2) listed in order from north to south are Pontinha, Manga Grande, Pastinho, Açudinho, and Onca. Pontinha

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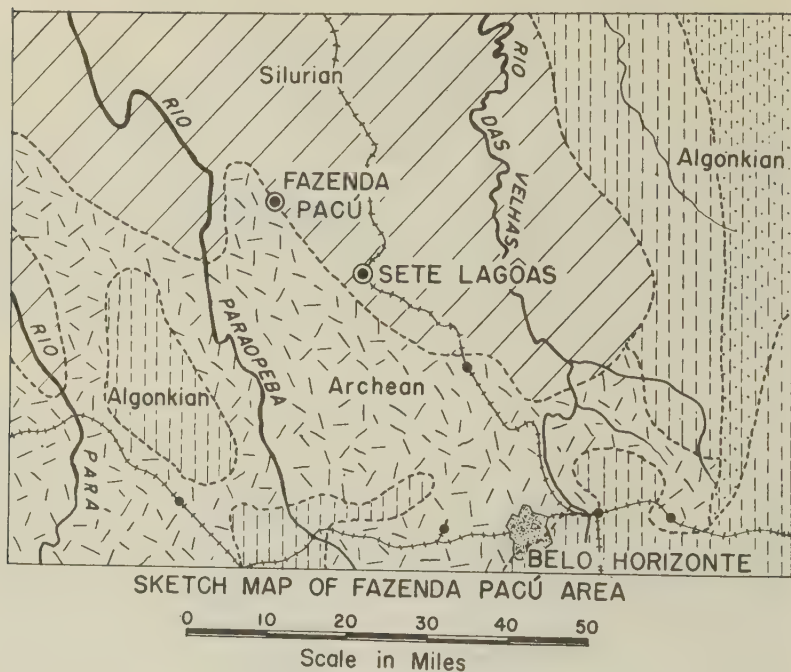


FIG. 1. The location of the quartz deposit.

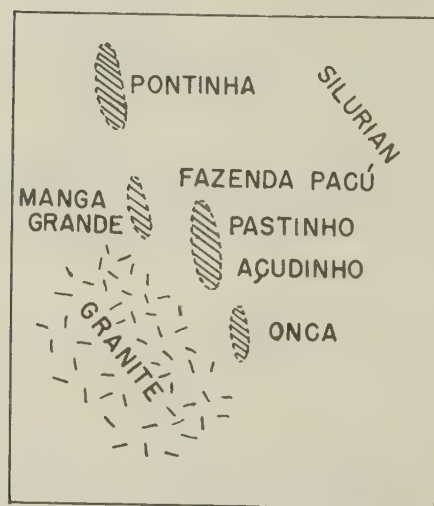


FIG. 2. Diagram showing the relative positions of the quartz bearing localities of Fazenda Pacú.



lies about five miles northwest of Manga Grande, which in turn is about one thousand feet south and west of the ranch house. Pastinho is a little more than one-half mile east of Manga Grande. Acudinho adjoins Pastinho on the southeast.

The workings at Onca are distributed along a zone 1300 feet long and 150 feet wide, while the areas mined in the other localities appear to be in each case from one half to three quarters as extensive. The maximum depth mined is about fifty feet. All of the work is carried on by hand and mule carts haul the spoil to nearby dumps. Dirt is hoisted from the bottom of the pits by shovel relay, as many as seven benches forming the side of some pits where workmen stand, each in turn shoveling dirt onto the bench above and thence into a mule cart. When water is encountered excavation stops, unless the water can be easily drained.

Quartz crystals occur in a soft matrix of decomposed material and are pried loose with picks. An abundance of quartz occurs in the material being mined, but only a small part of it is worth saving. This is piled and carried to the warehouse where it is sorted and trimmed for shipment by truck to Sete Lagoas and Belo Horizonte where further selection occurs.

Of the material mined not more than one crystal in a hundred is saved. Many of the crystals are cloudy or fractured, or occur in intergrown groups too small or too irregular to be satisfactory for electrical or optical use.

To be suitable for piezoelectric use as radio oscillators or for control in long distance telephony, the crystals must be sound individuals, uniform and clear. Twinning, inclusions, fractures, and intergrowth interfere with the utility of the material. In order to detect imperfections, all crystals are examined by a strong light; also in an illuminated box filled with immersion media and containing windows on opposite sides covered with crossed polaroid sheets.

#### ACKNOWLEDGMENTS

The writers wish to acknowledge the kindness of Mr. Redelvim Andrade and Dr. Newton Andrade for the courtesy of visiting Fazenda Pacú and their help in furnishing significant specimens. It is also a pleasure to acknowledge the assistance of the Carnegie Endowment for International Peace which has made this joint study possible. The kind cooperation of Dr. Luciano Jacques de Moraes, Director of the Departamento Nacional da Produção Mineral, Dr. Glycon de Paiva, Director of the Divisao de Fomento da Produção Mineral, and Dr. Anibal Alves Bastos, Director of the Divisao de Geologia e Mineralogia, in making available the facili-

ties of the government services, is greatly appreciated. We wish further to express our appreciation of the opportunity for discussion of the problem of the origin of the quartz with Dr. Arrojado Lisboa, chief of the Belo Horizonte section of the Fomento da Produção Mineral, and with his associate, Dr. Emilio Teixeira. We also wish to acknowledge the assistance of Dr. Djalma Guimarães, formerly with the department, who has written numerous contributions on Brazilian geology.

#### GENERAL GEOLOGY

Although a general account of quartz production at this locality has been published by Andrade (1941), little study has been made of the geological occurrence. In view of the present importance of this source of crystal quartz, it would seem worth while to record a number of geological observations in a preliminary description. It is regretted that our visit was too short to allow us to complete a study of the field relations and map the pits in detail.

The geologic map of the State of Minas Geraes by Djalma Guimarães and Octavio Barbosa (1934) indicates that Fazenda Pacú is located near the contact between the underlying Archean and the unconformably overlying Bambui series of supposed Silurian age. Along the road between Sete Lagoas and Fazenda Pacú one passes prominent exposures of Bambui sediments, chiefly limestone, but containing intercalated argillaceous strata.

The evidence of infrequent exposures appears to confirm the accuracy of the geologic map. It is possible that a small amount of the Algonkian phyllite, which occurs between the Archean and Silurian in places and has not been mapped in its entirety, might be present, although this is not considered likely, since the lithology is more typical of the Silurian.

Just west of Onca, the southern pit of the Fazenda Pacú group, is a good exposure of fresh granitic rock with float of biotite gneiss nearby. Building blocks have been cut for construction purposes from the granite. The fresh exposure forms part of a group of outcrops to be found in the vicinity and constitutes the nearest exposure observed containing unweathered granitic rock. The distance of the granite from the Onca pit is about 1300 feet. The formation is presumably Archean.

In evaluating the geological evidence concerning the origin of quartz at Fazenda Pacú, it should be kept in mind that the region is one in which the process of weathering has penetrated to an unusual depth. The matrix of the quartz crystals has been completely decomposed and it is now possible to pry them loose from a bonding of clay in all parts of the various deposits. The lower limit of rock decay has not yet been disclosed. Alteration appears just as intense fifty feet below as at the surface, and

it is claimed by local geologists that borings indicate weathering in some parts of Minas Geraes may extend three hundred feet or more below the surface.

The weathering effects have been irregular in their development, some rocks being little affected, others being completely decomposed. Subsequent erosion has removed the decomposed material irregularly, sweeping bedrock bare in some places and leaving scores of feet of rock decay in others. The quartz crystals are distributed through clay-filled fracture zones bordered by argillaceous strata or kaolinized granitic rock. Under such circumstances the nature of clays associated with the quartz at Fazenda Pacú is of considerable interest.

The general geology of Minas Geraes has been discussed by various authors. Harder and Chamberlin (1915) have furnished an excellent account of the geological features in the central part of the state, but unfortunately their observations did not include the area in the vicinity of Sete Lagôas. Branner (1919) in his outline of the geology of Brazil, written to accompany the geological map of the country, gives references to the work on Brazilian geology up to the time of his publication. Miller and Singewald (1919) have provided a most useful bibliography. Gerth (1932) has furnished a general discussion and a sketch map of the geological features of Minas Geraes. The geology of Brazil by de Oliveira (1940) with a general geological map furnishes a substantial revision of the earlier study by Branner. The most satisfactory geological map for general use in Minas Geraes is the state map by Guimarães and Barbosa (1934) referred to above.

#### NATURE OF THE DEPOSITS

A generalized section through the quartz pit at Onca is shown in Fig. 3. On the right, or east, is white and pink decomposed material believed to be kaolinized granite. The megascopic and microscopic texture compares favorably with the texture of the granite partly weathered in situ observed about 1300 feet west of Onca pit. It consists of specks of limonite in positions probably at one time occupied by the ferromagnesian minerals. Grains of anhedral quartz lie in approximately their original position and white kaolin occupies the positions of the original feldspars. The exposures of kaolinized granite in the quarry cuts exhibit a fracture pattern now a network of white kaolinite veins crisscrossing pink weathered granite. Cuts have not penetrated deep enough to encounter fresh granite in the workings.

Separating the decomposed granite from the quartz zone in the pits at Onca is a white kaolinized belt several feet thick which forms the foot-wall or east side of the vein system. The hanging wall or west side of the



vein system is made up of a well stratified argillaceous sediment. Exposures of a red shale were identified by Dr. Arrojado Lisboa as having the megascopic characteristics of the Silurian.

The sedimentary series is cut by vein quartz and in places veins have penetrated along bedding planes (Fig. 4). This feature is shown in several places at Onca where it is possible to observe parallel horizontal veins an inch or two in thickness and several inches to a foot apart. The veins are solid but grade into veins which yield crystals. The horizontal veins also curve gradually along the strike, eventually cutting across beds and joining those which are thick and steeply inclined.

The sedimentary series has been cut by tongue-like veins of quartz and in places has been distorted and displaced. Deformation of the Silurian strata is well shown near the larger quartz zone on the east side of the pit where the beds are steeply inclined, bent and broken in contrast to the moderately inclined and virtually unbroken strata on the edge of the vein-bearing area to the west. Solutions depositing quartz evidently followed the fracture pattern produced by the deformation, forming a stock-work of veins.

The clay matrix of the quartz is now largely kaolin. Veins contain decomposed fragments of argillaceous wall rock. Manganese and iron are present in minor amount. Sericite, so common in quartz veins, may have been a prominent original constituent, but if so it has not resisted the kaolinization.

Overlying the section just described is a mantle of soil containing fragments of quartz and occasionally loose crystals, the whole forming surface gravel.

Gouge and folding along the side of the main quartz mass (Fig. 5) indicate movement which is also shown by the tilting and, in places, breaking of sedimentary strata. It seems unlikely that the movement was one of great magnitude or the sediments would have been more completely broken. Also, the overlying Silurian strata to the east are more or less horizontal.

The quartz bearing zone appears to strike in general north-south and dips steeply to the west at 60 degrees or more. The trend appears to be the same in each of the pits where material in situ is to be found. Also in each pit a large vein appears to be bordered by a group of smaller veins on the hanging wall side. At times small veins penetrate the decomposed granite of the footwall. On the whole, however, except along the margin of the main crystal zone, where fracturing and vein filling have been greatest, the granite is free from crystals or vein quartz. It seems likely that careful geologic mapping might disclose a vein pattern, since the

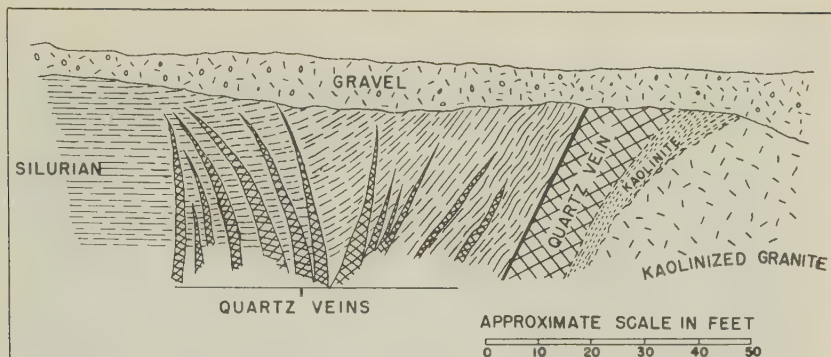


FIG. 3. A generalized section through the quartz pit at Onca, Fazenda Pacú.

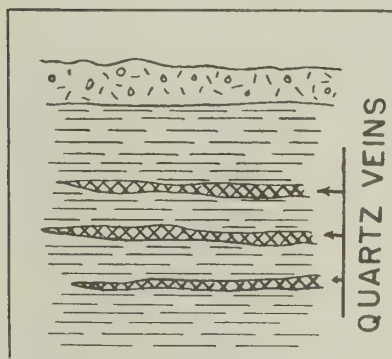


FIG. 4. Quartz veins formed by penetrating the shale series along bedding planes.

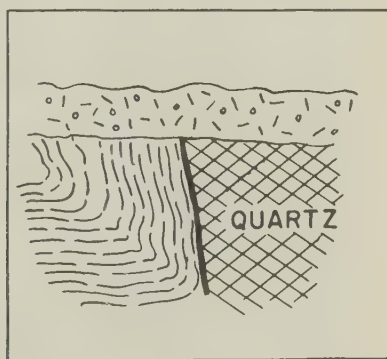


FIG. 5. An exposure about 20 feet across on the quarry wall at Onca showing the deformation of the shale series bordering a quartz vein.

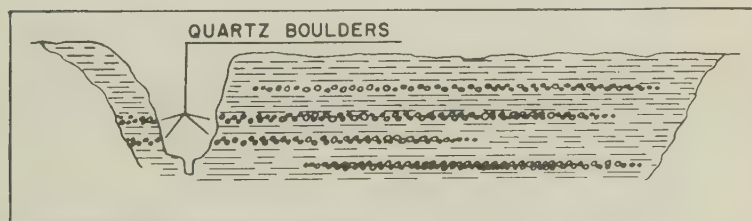


FIG. 6. A quarry face at Açudinho about 100 feet long where quartz crystals occur as rounded boulders forming layers separated by several feet of clay.

relations in the pits where the vein is visible are so similar. Such a study should also be useful in prospecting for intermediate deposits which may be needed to carry on production when mining in pits now being worked reaches an economic lower limit. Several vein systems may exist, but the alignment of operations at present indicates a single set of veins. The pattern of the system should give the key for prospecting the intermediate area between pits.

In addition to the pits where decomposed veins are being mined *in situ*, a thick deposit of clay and quartz gravel has accumulated at Acudinho. Here quartz occurs in crystals with rounded water worn edges, rounded boulders and small pebbles. These form layers from a few inches to two feet in thickness and are separated by layers of sedimentary clay several feet thick (Fig. 6). Both the clay and crystal boulder layers are horizontal and are exposed for a section 150 feet in length and 35 feet in depth. Nine boulder layers are reported to occur, each separated from the one above and below by several feet of stratified clay. These layers provide some of the best crystals to be found, since the process of water wearing has eliminated the fractured crystals and has reduced the number of imperfections.

#### CHARACTER OF THE QUARTZ

The quartz zones contain clear crystals, cloudy or milky quartz, clusters of crystals, interlocking crystalline masses, clay material, black manganese oxide stain, limonite, and occasional streaks of goethite. They consist for the most part of heterogeneous masses of quartz in clay.

Crystals are singly terminated with few exceptions and vary from a diameter of a fraction of an inch to prisms a foot thick and three feet long. Nearly all crystals are several times as long as thick, although Dr. Andrade presented the writers with a doubly terminated crystal several inches thick having well developed rhombohedral faces and thin almost negligible prism faces. Such a crystal is rare for the deposit. A clear crystal weighing 330 pounds has been described by Andrade (1941) as having been found at this locality.

Large quartz crystals have been found in a number of localities in Brazil. A mass of clear optical quartz weighing approximately one thousand pounds was exported from Minas Geraes in 1940. Numerous cloudy crystals up to three feet in length and a foot in diameter have been found at Fazenda Pacú.

The largest crystal observed by the writers is the great smoky quartz crystal in the Feira Permanente de Amostras at Belo Horizonte (Figure 10). It deserves a place among the largest quartz crystals ever found. This crystal was discovered at Ariranha in the district at Pavao, the muni-



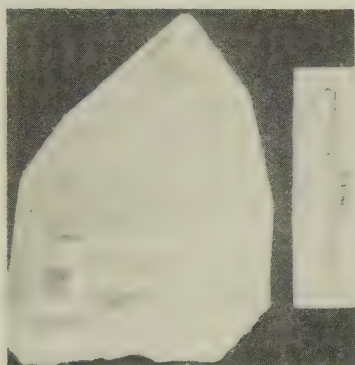


Figure 7



Figure 8



Figure 9



Figure 10

FIG. 7. Quartz crystal from the Diamantina district, Brazil, containing thin plates of altered itacolumite.

FIG. 8. An enlarged view of a portion of Figure 7.

FIG. 9. A quartz crystal from Minas Geraes, Brazil, containing kaolinite believed to have crystallized along with the quartz.

FIG. 10. An unusual quartz crystal from Teofilo Otoni, weighing about five tons, thought to be pegmatitic in origin.

cipality of Teófilo Otoni in Minas Geraes, Brazil. It is 7 feet, 2 inches in height, 11 feet, 2 inches in circumference and weighs more than five tons.

Crystals were observed showing inclusions of kaolinite and itacolumite reported to have been found in the Diamantina district. Rutile or chlorite inclusions, if present, are uncommon. Turbidity, fracture and twinning appear to be the most common defects. Thin sections of turbid crystals show an abundance of fluid inclusions, a sufficient number in fact to account for the turbidity.

#### ORIGIN OF THE CRYSTALS

Because of the prevalent rock decay, the origin of quartz in Brazil is frequently uncertain. Dr. Luciano J. Moraes (1934) who has examined many crystal localities including the Serra do Cabral, Serra Mineira, and Serra Itacambira, has considered the crystals to occur chiefly in pegmatites, the origin being inferred from the presence of a large quantity of kaolinized material thought to have resulted from the decomposition of pegmatite. At Fazenda Pacú, however, coarse feldspar crystals, tourmaline, garnet, mica, and beryl, the common constituents of Brazilian pegmatites, are conspicuous by their absence. In addition, the structure of the mass indicates little likelihood of these minerals having been once present and later decomposed by weathering.

Dr. Djalma Guimarães who has studied the quartz of the Serra Mineira district in connection with investigations of the origin of the diamond, inclines to the opinion the quartz of the Diamantina district should be considered as vein quartz.\* Examination of Silurian areas, he reports, reveals sulphide-bearing quartz veins in the limestone in the proximity of crystal localities. He also suggests that the quartz which has invaded the Silurian, being younger, shows less strain and twinning than is usually found in older pre-Silurian occurrences.

With quartz occurring over such a wide area in Brazil it is only natural to expect to find rock crystal with several types of occurrence. With this in mind, the present discussion centers around the locality of Fazenda Pacú.

The weight of evidence concerning the pressure-temperature conditions of formation of the quartz at Fazenda Pacú points toward moderate temperature vein-forming conditions. The prevalence of fluid inclusions indicates the precipitation of quartz from aqueous solutions, a criterion thus interpreted since the classic work of Sorby (1858). These appear to be both primary and secondary, according to the interpretations of fluid inclusions advanced in the studies of Newhouse (1932). The abundance

\* Personal communication.

of large crystals having a minimum of twinning with a simple prismatic form favors the conclusion that the original solutions yielded alpha-quartz (Wright and Larsen, 1909). Open cavities in the veins and lack of compaction of the wall rock suggests a moderate load of overlying sediment and low pressures.

A quartz crystal from an unknown locality in the region (Fig. 9) contains abundant inclusions of kaolinite. The inclusions form accordion-like clusters, each several millimeters in length. Some clusters are completely surrounded by the silica. They are concentrated at the base of the crystal where it was attached to the enclosing wall and extend along one side. A large part of the crystal, however, is clear quartz, but intricately twinned as shown in thin section. Since the hydration curve of kaolinite breaks sharply at  $450^{\circ}\text{C.}$ , it seems likely that the temperature of formation of the crystal was lower, or the kaolinite would not have retained its form as shown in thin section.

In the last hundred years a considerable number of experiments have been made in which alpha-quartz has been crystallized from solution. Crystallization of quartz has been claimed in some experiments as low as  $180^{\circ}\text{C.}$ , and the mineral has apparently been formed by a number of investigators at temperatures between  $200^{\circ}\text{C.}$  and the inversion temperature. The literature on this subject has been reviewed by Morey and Ingerson (1937). A survey of these experiments would indicate the likelihood that quartz might easily form in nature from thermal solutions within the temperature range indicated.

Freyberg (1934) has discussed the occurrence of quartz in the Serra do Cabral, a mountain range some distance northwest of Diamantina in the province of Minas Geraes. From his description it would appear that crystals occur in areas of white quartzite belonging to the Itacolumite series. The deposits of clear crystal quartz tend to form along the crests of anticlines, and apparently the clear quartz crystals have been crystallized from solutions which have derived silica from the quartzite.

Walls (1929) has discussed the origin of crystal in the vicinity of Diamantina. He believes that crystals have been formed by solution as a secondary product derived from quartz present in great beds of quartzite. The solutions he considers thermal in character, carrying such constituents as would result in the formation of extremely fine potash mica and at the same time would also produce large clear quartz crystals.

Accompanying photographs of a quartz crystal may typify this occurrence. The crystal unfortunately was not found in place, but was considered by those familiar with the Diamantina district to have come from that locality. Two views of the crystal are shown in Figs. 7 and 8. The



second view (Fig. 8) is a close-up of a portion of the first. Aside from the inclusions there is nothing unusual about the crystal. The inclusions, however, represent a group of more or less separated layers believed to be undigested portions of thin bedded quartzite from the Itacolumite formation in which crystals are known to occur. The stratification is suggestive and is well exhibited, particularly on the base of the crystal where a cut was made to obtain a chip for a thin section. The thin section shows the presence of sericite in the layers.

It would appear from Walls' description of quartz in the Diamantina district that large crystals of clear quartz form along fracture zones which have been filled with fine sericite mica, the quartz crystals being oriented with their *c*-axes normal to the walls of the fractures. The evidence from the crystal described above would appear to support his conclusion that the crystals were precipitated from silica-bearing solutions, the silica being derived in a large degree from the enclosing wall rock.

#### CONCLUSIONS

While rock crystal of pegmatitic origin may be common in Brazil, it seems reasonable to conclude that the crystal at Fazenda Pacú has resulted from vein forming solutions. These have forced their way upward along fractures. Crystals have formed in the gouge and in openings in the broken strata at or near the boundary between the Bambuí sediments and the Archean granite. Actual vein forming conditions have probably been similar to those existing in other parts of the world where large accumulations of vein quartz have formed from solution. Brazil has been so much more productive of crystal quartz not merely because of large and widespread accumulations, but chiefly because of the weathering which has reduced the associated matrix to a clay. Under such conditions it is possible to select by inexpensive hand labor the one crystal in each hundred or more worth saving. The widespread distribution and the occasional formation of large, clear crystals are features which should not be minimized, but by themselves could hardly be considered limited to Brazil.

The temperature of formation was probably moderate, the quartz belonging to the alpha-phase. It may have formed at temperatures considerably below the inversion point. Pressure was probably a minor factor. Although not considered pegmatitic, the solutions might have yielded pegmatites at depth. In any event, it seems difficult to conceive of solutions being other than hypogene in a region of such widespread metamorphism.

## REFERENCES

- ANDRADE, NEWTON, Producao e comercio do cristal: *Brasil Mineral*, Ano II, Num. 7, 40-43 (1941).
- BAUER, MAX, (translated by L. J. Spencer), Precious Stones, 478 (1904).
- BRANNER, J. C., Outlines of the geology of Brazil: *Geol. Soc. Am. Bull.*, **30**, 189-337 (1919).
- FREYBERG, B., Ergebnisse geologischer Forschungen in Minas Geraes (Brasil), 115; 304 (1932).
- GERTH, H., Geologie Sudamerikas, **I**, 22 (1932).
- GUIMARÃES, DJALMA, AND BARBOSA, OCTAVIO, Mapa geologico do estado de Minas Gerais: *Dept. Dos Servicos Geografico e Geologico*. Anexo ao Boletim 3. (Belo Horizonte) (1934).
- HARDER, F. C., AND CHAMBERLIN, R. T., The geology of central Minas Geraes, Brazil: *Jour. Geol.* **23**, 341-378; 385-424 (1915).
- LEONARDOS, O. H., AND DE MORAES, L. J., Quartz: *Dept. Nacional da Produção Mineral Avulso* No. **11**, 1-16 (1936).
- MILLER, B. L., AND SINGEWALD, J. T., The Mineral deposits of South America. McGraw-Hill Book Co., New York (1919).
- MOREY, G. W., AND INGERSON, EARL, The pneumatolytic and hydrothermal alteration and synthesis of silicates: *Econ. Geol.* (suppl.) **32**, 607-761 (1937).
- NEWHOUSE, W. H., The composition of vein solutions as shown by liquid inclusions in minerals: *Econ. Geol.*, **27**, 419-436 (1932).
- DE OLIVEIRA, AVELINO I., Quartz: *Dept. Nac. da Produção Mineral Relatorio da Directoria*, 72 (1917).
- , Mappa geologico do Brasil: *Dept. Nacional da Produção Mineral* (1938).
- SORBY, H. C., The microscopical structure of crystals: *Quar. Jour. Geol. Soc. London*, 453 (1858).
- WALLS, ROBERT R., Rock crystal and diamond pipes in Brazil: *Geol. Mag.*, **66**, 111-116 (1929).
- WRIGHT, C. W., Mineral resources, production, and trade of Brazil: *U. S. Bur. Mines, Foreign Minerals Quarterly*, **4**, 62-67 (1941).
- WRIGHT, F. E., AND LARSEN, F. S., Quartz as a geologic thermometer: *Am. Jour. Sci.* (4), **27**, 421-447 (1909).

## CRYSTALLOGRAPHIC NOTES: CRISTOBALITE, STEPHANITE, NATROLITE

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### ABSTRACT

Cristobalite crystals with cubic habit are reported from Two Rivers, California.

A study of doubly terminated crystals of stephanite shows pronounced diversity in the forms on opposite ends of crystals, and further confirms the hemimorphic character of this mineral. One probable new form,  $\{17.8.17\}$ , was noted as occurring three times on the measured crystals.

Natrolite crystals in which the square prismatic habit is due to the  $a$  and  $b$  pinacoids rather than the prism, and which are rather complexly terminated, are described. The typical assemblage of forms is:  $a, b, m, p, z, y, o, \beta, \alpha$ . The new form  $t\{351\}$ , appeared on one crystal.

### CRISTOBALITE

Through the courtesy of Dr. Cordell Durrell, of the University of California, Los Angeles, the writer received a specimen of olivine basalt carrying cristobalite crystals on its fracture surfaces. The material was collected by Dr. Durrell near Two Rivers, Plumas County, California.

The normal habit of cristobalite is octahedral, and usually the octahedron is the only form present, although other forms have been reported, both on natural and on synthetic crystals. Rosicky<sup>1</sup> describes cristobalite from Bohemia in clear or cloudy octahedra with small modifying faces of  $\{100\}$ ,  $\{110\}$ , and  $\{331\}$ . Weil<sup>2</sup> synthesized cristobalite in cubo-octahedra, never as simple octahedra.

The crystals from Two Rivers occur thickly distributed on fracture surfaces of the basalt, as small individuals or groups; none of the crystals are over 0.5 mm. in size. Most of them appear as clusters of individuals, showing well-developed cubic faces. In these clusters the crystals are sometimes interpenetration twins according to the spinel law, and at other times they occur as radiating or sub-parallel groups. Twinning has been reported by Gaubert<sup>3</sup> on cristobalite from Mayen, in the Eifel district. One single crystal was found in the Two Rivers specimen, which showed a balanced development of cube and octahedron. Its faces were sufficiently smooth so that the forms could be checked on the reflection

<sup>1</sup> Rosicky, V., Die drusen Minerale des Andesites von Nezdence in Mähren: *Festschrift, V. Goldschmidt*, Heidelberg, 229-242 (1928).

<sup>2</sup> Weil, R., Synthèse de la cristobalite par voie humide: *Compt. Rendus Acad. Sci.* (Paris), **181**, 423-424 (1925).

<sup>3</sup> Gaubert, P., Sur la cristobalite de Mayen: *Bull. Soc. Min. de France*, **27**, 242-245 (1904).



goniometer. Descriptions of occurrences of cristobalite other than those noted above, mention only the octahedron, so that the cubic habit is clearly quite uncommon, and on that account worth recording.

## STEPHANITE

Some time ago a collection of unlabelled specimens was received at the University of California, Los Angeles, among which was one ore specimen showing numerous well developed crystals of a metallic mineral. These were examined carefully in the hope of obtaining material suitable for a crystallographic collection. Chemical tests and crystal measurements identified the mineral as stephanite, and it was further noted that a number of the crystals were doubly terminated. This offered an opportunity of checking further the hemimorphic character of this mineral, and accordingly fifteen crystals were carefully measured on the goniometer, with the results detailed below.

Five of the measured crystals are sufficiently developed so that measurements could be made on both terminations. Almost invariably the

TABLE 1

Crystal #15

Form	Number of faces	Measured (average)				Calculated	
		$\phi$	var.	$\rho$	Var.	$\phi$	$\rho$
<i>b</i> 010	1	0°00'		90°00'		0°00'	90°00'
$\pi$ 130	1	27 56		90 00		27 55	90 00
<i>u</i> 350	1	44 54		90 00		43 38	90 00
<i>o</i> 110	3	57 47	(13')	90 00		57 49	90 00
<i>l</i> 023	2	0 00		24 24½	(04½')	0 00	24 33
<i>k</i> 011	2	0 00		34 27	(03')	0 00	34 25
<i>d</i> 021	2	0 00		54 13	(27')	0 00	53 52
$\beta$ 101	1	90 08		47 28		90 00	47 26
<i>m'</i> 113	3	57 47½	(13½')	23 19	(03')	57 49	23 13
<i>h'</i> 112	3	57 47	(11')	32 51	(15')	57 49	32 45
<i>l'</i> 223	1	57 57		40 36		57 49	40 37
<i>P'</i> 111	3	57 47½	(13')	52 08	(04')	57 49	52 08
<i>r'</i> 221	2	57 53	(04')	68 34	(24')	57 49	68 46
<i>A'</i> 313	1	78 02		48 04		78 09	48 03
<i>C'</i> 17.8.17*	2	73 23	(03')	48 37	(01')	73 30½	48 38
<i>w'</i> 131	1	27 56		66 39		27 55	66 44
$\rho''$ 241	1	38 32		74 18		38 28	74 03

\* New form.

crystals are multiple, being composed of two or three individuals as interpenetration twins on the usual twinning plane  $\{110\}$ , but in most cases it was possible to distinguish the individuals readily, and compare terminations directly. No evidence of twinning on  $\{001\}$  was seen, and any striations on prism faces were either vertical or horizontal. The quality of the reflections was for the most part excellent, so that very accurate readings could be made, and there is no reason to suppose that observational errors have any effect on the conclusions which were reached. The quality of the readings is shown in the example given below, which is typical of many other crystals measured.

### NEW FORM

A form was observed twice on this crystal and once on the crystal in twinned position to this, the angular position of which is given below, with calculated angles for neighboring indices. The signals fall in the zone between  $\{101\}$  and  $\{111\}$ .

Observed			Calculated		
Quality	$\phi$	$\rho$	Form	$\phi$	$\rho$
<i>D</i>	73°20'	48°38'	212	72°32½'	48°47'
<i>B</i>	73 26	48 36	17.8.17	73 30½	48 38
<i>D</i>	73 52	48 48	13.6.13	73 48½	48 36
average	73 33	48 41	11.5.11	74 02½	48 33½
			949	74 23	48 31
			525	75 53	48 20

From an inspection of these values it is difficult to pick an appropriate symbol for the form. As is seen above, the calculated values for  $\{212\}$  and  $\{949\}$  differ about equally from the measured figures, and the values most closely in agreement are for forms with complex indices. In view of the good quality of the faces, the accuracy of setting of the crystal, and the fact that many recorded stephanite forms have complex indices, the writer is inclined to choose  $\{17.8.17\}$  for this form, rather than the much simpler  $\{212\}$ , or even  $\{949\}$ .

### HEMIMORPHISM

The hemimorphism of stephanite was observed first by Miers,<sup>4</sup> who noted the polarity of prism faces as revealed by the striations parallel to

<sup>4</sup> Miers, H., The hemimorphism of stephanite: *Mineral. Mag.*, 9, 1-4 (1889).

the edge  $110 \wedge 731$ , and the presence of twinning on  $\{001\}$ . D'Achiardi<sup>5</sup> observed differences in size between  $\{001\}$  and  $\{00\bar{1}\}$ , and noted that the upper termination carried many  $0kl$  faces, but that only  $\{02\bar{1}\}$  appeared on the lower end. He also observed  $\{13\bar{2}\}$  on the bottom only. Soriano<sup>6</sup> also observed a difference in forms on opposite ends of a well developed crystal, and lists the following forms as appearing only on one end:  $\{122\}$ ,  $\{133\}$ ,  $\{114\}$ ,  $\{155\}$ ,  $\{152\}$ ,  $\{134\}$ . Further evidence of hemimorphism has been supplied by Taylor<sup>7</sup> in  $x$ -ray studies, and in morphological analysis according to Donnay's method. These studies rule out on theoretical grounds the possibility of structure class 222, even when the horizontal plane is not a plane of morphological symmetry.

The writer observed the distribution of faces on opposite terminations of seven distinct crystals, in most cases noting faces occurring above and below identical prisms or brachydomes, so that direct comparison was possible. These observations showed that a considerable number of faces appear on only one termination of a given crystal. There seem, however, to be few forms which do not at one time or another appear on both ends of the same crystal. There is apparently no criterion by which the upper and lower ends may be distinguished, as there seems to be no consistent variation in size or quality of faces on the two ends. The omissions are in general certainly not due to imperfect crystal development, because their positions are nearly always flanked on either side by faces of the same zone.

$\{223\}$  appears to be the only form never observed on both ends of any crystal or group, occurring four times, only on what the writer has oriented as the lower termination.  $\{133\}$  occurs four times also, but twice above and twice below (one pair in the same group although not on the same crystal). The faces of the zone  $[101-111]$  appear only above, with the sole exception of  $\{101\}$ , which appears below in one instance.  $\{134\}$  occurs four times above and twice below. In the brachydome zone,  $\{023\}$ ,  $\{011\}$  and  $\{021\}$  appear consistently both above and below, and other faces occur indiscriminately in either position. These results do not correspond with those reported by Soriano and D'Achiardi, as several brachydomes do occur on both ends, and further, there is no noticeable

<sup>5</sup> D'Achiardi, G., Emimorphismo e geminazione della stephanite del Sarrabus: Abstr. in *Neues Jahrb. Min., etc.*, **II**, 338 (1902).

<sup>6</sup> Soriano, V., Los Cristales de Estefanite de Hiendelaencino (Guadalajara): *Bol. Soc. Esp. de Hist. Nat.*, **31**, 1, 49-67 (1931).

<sup>7</sup> Taylor, E. D., Stephanite morphology: *Am. Mineral.*, **25**, 327-337 (1940).



difference in size of the faces on opposite ends. The form {132} was not observed on any of the writer's crystals, and so cannot be compared with their results.

In spite of the inconsistency of these observations, the general inequality of terminations helps to confirm the observed hemimorphism of stephanite.

#### NATROLITE

Several specimens of natrolite from the headwaters of the San Benito River, San Benito County, California, near the famous benitoite locality, carry large crystals showing a rather unusual complexity of habit. The crystals occur in open vugs in a vein of massive natrolite in what is apparently serpentine, although not enough of the wall rock was preserved on the specimens to make this determination certain. The crystals are long prismatic, square or rectangular in cross-section, reaching a maximum length of 3 cm., with a thickness of 0.2–0.3 cm. Many of the crystals are terminated by a group of shiny faces. A considerable number of crystals were examined, and a dozen measured on the goniometer. The signals were, generally, of high quality, and the resulting readings very accurate. The measurements on a typical crystal, and the calculated values for the angles, are given in Table 2.

TABLE 2

Form		Number of faces	Measured				Calculated	
			$\phi$ average	var.	$\rho$ average	var.	$\phi$	$\rho$
<i>a</i>	100	2	89°59'		90°00'		90°00'	90°00'
<i>b</i>	010	2	0 03	(02')	90 00		0 00	90 00
<i>m</i>	110	2	45 31	(02')	90 00		45 32	90 00
	110	1	46 17		90 00			
	(very poor face)							
<i>p</i>	111	4	45 34½	(05½')	26 46	(02')	45 32	26 42
<i>z</i>	331	3	45 28	(03½')	56 35	(01')	45 32	56 28
<i>y</i>	131	3	18 45	(04')	48 16	(01')	18 26	48 06
<i>o</i>	151	1	11 31		61 34		11 31	60 56
$\beta$	311	2	71 58½	(04½')	48 43½	(04½')	71 53	48 34
$\alpha$	511	2	78 57	(02')	61 30	(01')	78 54	61 20

The square cross-section of these crystals is due to the strong development of the pinacoids {100} and {010}, while the prism faces are always

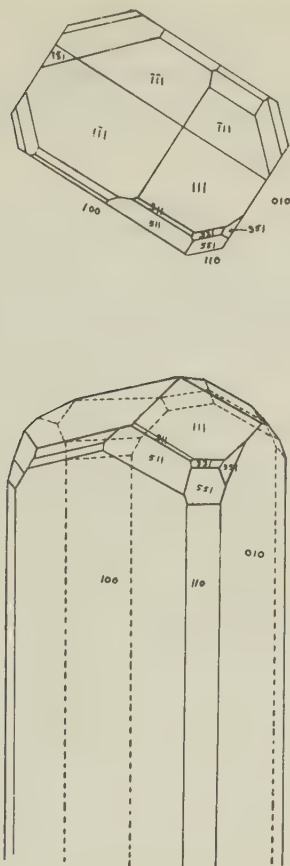


FIG. 1. Natrolite.

narrow, and occasionally missing. The most prominent terminal faces are those of  $\{111\}$ , which are modified by narrow faces of several other pyramids. The usual habit of crystals from this locality is shown in Fig. 1. The relatively uncommon form  $o\{151\}$ , found by Phillips,<sup>8</sup> was observed on three crystals, in each case as a very narrow face.

#### NEW FORM

A small face, occurring only once on the measured crystals, but smooth and giving a good signal, lies in excellent position for  $\{351\}$ , which thus

<sup>8</sup> Phillips, A. H., Some new forms of natrolite: *Am. Jour. Sci.*, (4) **42**, 472 (1916).

far has not been recorded for natrolite. Since this face has been reliably measured, and lies near no other face with simple indices, it may be considered as reasonably established. It has been given the designation *t*. The observed and calculated angles for this new form are given below:

	Measured		Calculated	
	$\phi$	$\rho$	$\phi$	$\rho$
<i>t</i> 351	31°29'	64°20'	31°26'	64°10'

#### ACKNOWLEDGMENT

The writer wishes to express his thanks to J. N. Truex who collected the material and whose gift made possible the foregoing measurements.



# AN UNUSUAL ASYMMETRICALLY BANDED FISSURE VEIN

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## ABSTRACT

An asymmetrically banded fissure vein from Clausthal, Germany, is described and illustrated. The writer shows that the veins could not have developed by deposition from homogeneous dilute or concentrated solutions, from colloidal solutions by processes of replacement, or by reopening and filling. The unique features of the veins are explained on the basis of immiscible solution pairs which originated, before splitting, as the result of fractionation of an earlier concentrated mineral solution.

## INTRODUCTION

The banding of minerals found in fissure veins was among the natural phenomena which first attracted the attention of geologists and mineralogists. Banding in veins is usually of a symmetrical character, that is, the structure of the vein from one wall to the center consists of bands of the same materials and order of arrangement as from the opposite wall to the center, although the corresponding bands may not all be of the same thickness or regularity. Bands of an asymmetrical character are uncommon unless a vein is reopened nearer one wall than the other. Replacement processes may occasionally be active in producing unequal banding, but the extent of the operation is probably rather limited. Asymmetrical banding produced by reopening of an earlier vein is usually easy to detect and the process of formation is clear and understandable.

Banding of the type described below appears to be very unusual if not a unique occurrence in known mineral deposits.

## DESCRIPTION OF THE VEINS

In 1926 while engaged in an investigation on the cause of banding in fissure veins based on the evidences available from a study of the vein specimens in the suites of ores in the Laboratory of Economic Geology at Cornell University,† the writer became particularly interested in a veined ore slab, Fig. 1, from the Rosenhof shaft at Clausthal, Germany. The specimen is about 12"×18" in area and 4" thick. It consists of a number of more or less parallel veins containing chiefly galena, siderite and quartz in their decreasing order of abundance, together with a very small amount of chalcopyrite and sphalerite.

\* Now on leave of absence from Smith College and serving in the United States Army as a Captain in the Ordnance Department.

† This dissertation on a phase of filled-fissure veins is the third resulting from graduate study at Cornell University, 1925-1929.

The wall rock consists chiefly of fine-grained quartz and sericite of sedimentary origin. It has undergone fracturing and undoubtedly much alteration prior to the introduction of the vein-forming solutions. The vein systems are complex and their exact relationships are not always exhibited. However, many important features are clearly shown on the specimen although the veins do not always photograph as distinctly as one may desire.

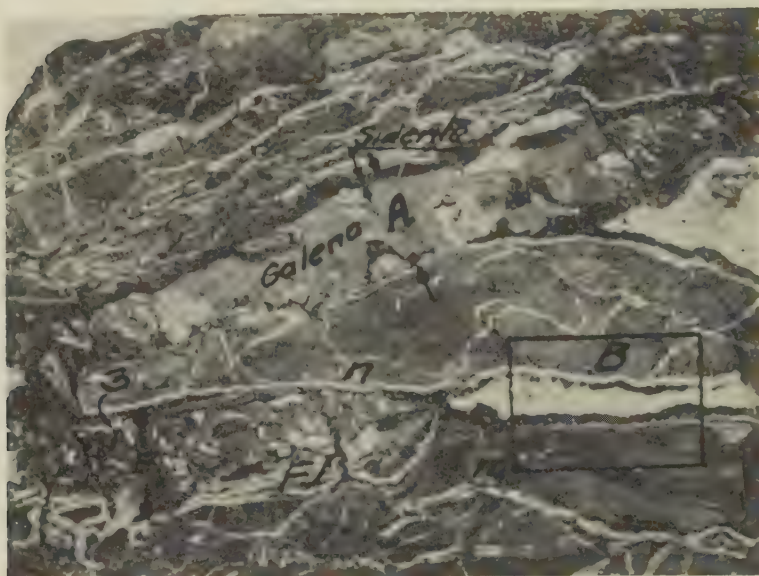


FIG. 1. Front view of ore slab from Rosenhof shaft, Clausthal, Germany, showing intricate system of veins. The larger ones, *A* and *E*, are the earlier while vein *B* is later and intersects vein *E* at *m-n*. The smaller veins are probably contemporaneous with *B* as they cut vein *E* at *F* and *G*.  $\times = 0.30$ .

The first veins to develop appear to be those indicated at *A* and *E*, Fig. 1. These are branches of the same vein and they join at the left edge of the illustration. The sharply defined vein *B* intersects vein *E* along an irregular line *m-n* making an angle of about  $45^\circ$  with each other. The network of small veinlets appears to be later than *A* and *E* and probably are contemporaneous with vein *B* as shown at *F* and *G*, Fig. 1, where the small veins intersect the earlier ones. The earlier and larger veins contain predominantly galena and siderite while the later network of small veins consists chiefly of siderite and quartz, with a little galena.

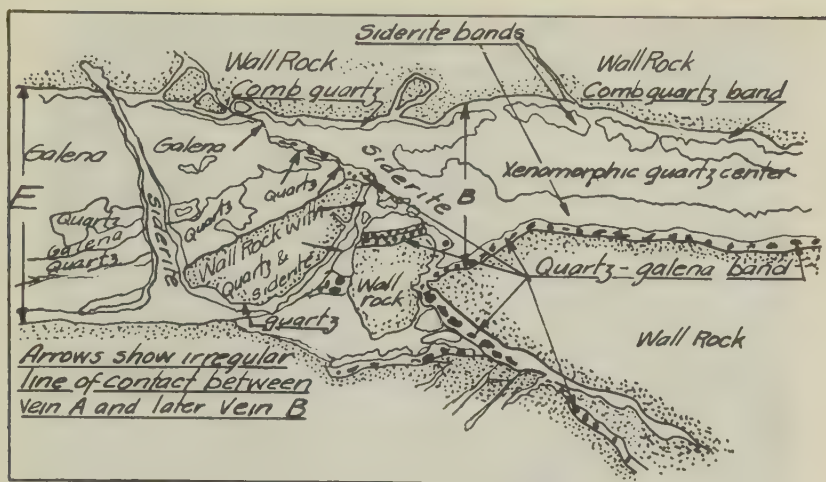


FIG. 2. Sketch of part of vein B, traced from polished surface of specimen, Fig. 1, showing the relationship of veins E and B together with the asymmetric banding of vein B and the small associated veins. About  $\frac{1}{2}$  natural size.

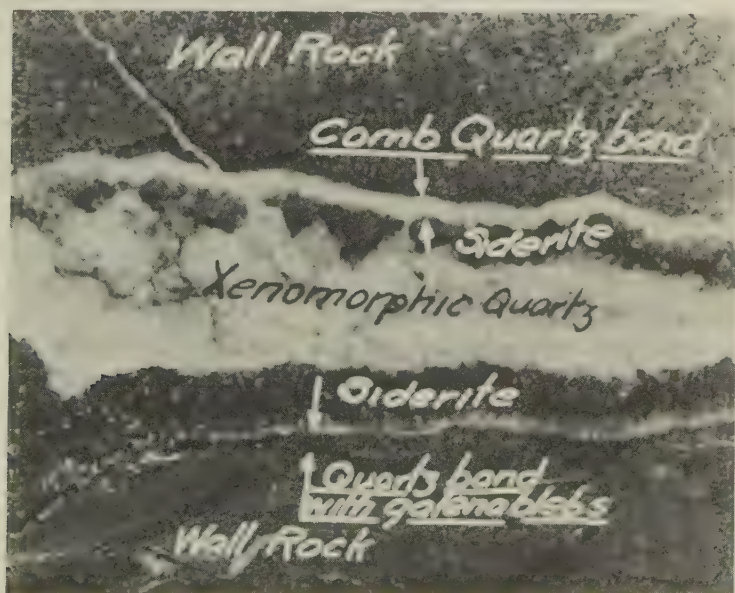


FIG. 3. An enlarged portion of vein B, Fig. 1, showing in more detail the relationship of the several bands producing the asymmetrical banding.  $\times = 1.41$ .



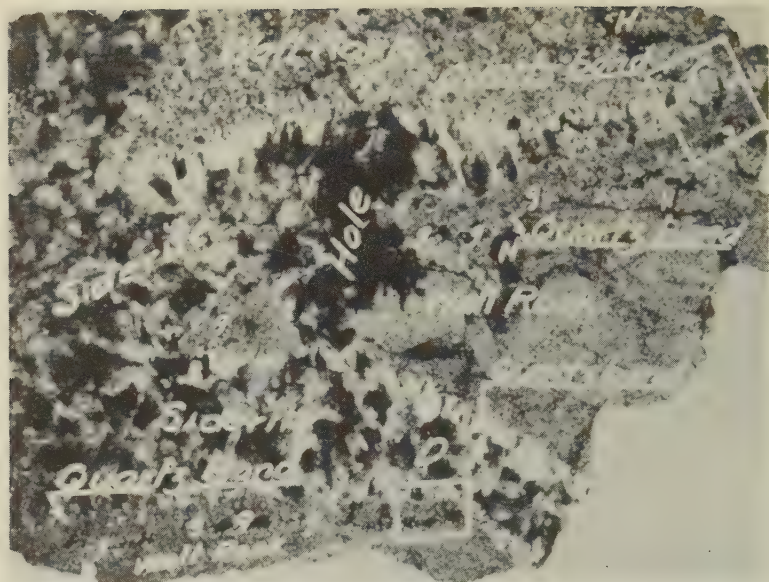


FIG. 4. Photomicrograph in crossed polarized light of a large thin section of two intersecting veins occurring on the back side of the specimen at right end of vein *B*, Fig. 1. Area *C* is shown enlarged in Fig. 5, and area *D* is shown enlarged in Fig. 6. *H*=holes. The dark areas indicated by *g* are galena blebs in the fine-grained quartz band.  $\times=2$ .

The initial deposition on the wall rock is usually a thin band of quartz followed by siderite and galena. The early deposition of quartz, a common feature in many veins, is probably due to the effect of the solid phase of quartz in the wallrock. Vein *B* and the associated smaller ones which are more or less parallel to the principal veins are the ones of particular interest owing to their marked asymmetrical banding shown in detail in the photomicrographs, Figs. 4, 5, and 6.

In the description of such complex vein systems and vein structures adequate photographic illustrations are of the utmost importance. In this instance a general view, less the irregular edges of the specimen, is shown in Fig. 1 and a detailed sketch of the most important part of the specimen traced from the polished surface on tracing paper appears in Fig. 2. The area outlined at *B* in Fig. 1 is reproduced to a larger scale in Fig. 3. The section for the photomicrograph shown in Fig. 4 was obtained from vein *B* on the opposite side of the specimen, Fig. 1, at the right. Areas *C* and *D* of Fig. 4 are reproduced on a larger scale in Figs. 5 and 6, respectively.

The unique feature of the later group of veins is the outstanding asymmetrical character of the banding and the mineralogical relationship of





FIG. 5. Area C of Fig. 4 is shown in this illustration in crossed polarized light illustrating the texture and structure across a small vein. *H* = holes. *Ga* = galena.  $\times = 11.8$ .

one band to another. Although the bands in contact with the walls consist largely of quartz, Fig. 5, nevertheless the structure, size and orientation of the constituent grains are entirely different in each. In addition to the quartz, the lower band contains a considerable amount of galena which occurs as blebs within the fine-grained, mostly xenomorphic quartz, while the quartz band in contact with the opposite wall consists entirely of comb quartz, the grains of which are oriented normal to the wall. The center of the smaller veins are filled with siderite. In the larger asymmetrically banded vein shown at *B* in Fig. 1, and on a larger scale in Fig. 3, the siderite occurs in bands following the first quartz bands and it is in turn followed by a central filling of xenomorphic quartz grains, the siderite bands being of unequal thickness, the larger band being at the bottom of the vein as shown in the illustrations. It will be observed that the siderite bands in vein *A* are unequal in width and are not continuous.

There are two features of the fine-grained quartz-galena band that are especially significant criteria concerning the origin of the banding. These are (1) the unequal and random development of an irregular comb

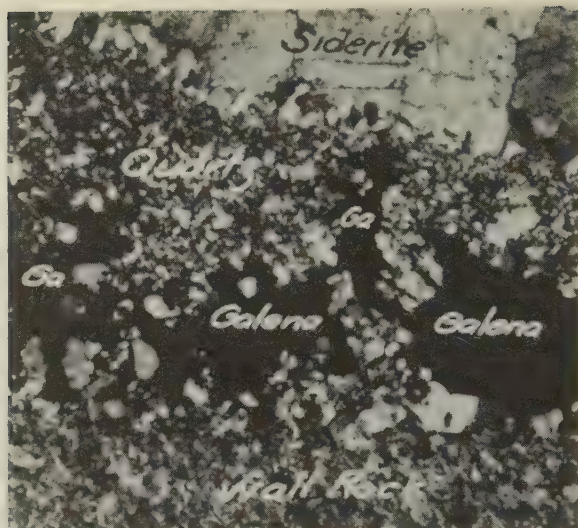


FIG. 6. Area *D* of Fig. 4 is shown in this illustration in crossed polarized light. The subhedral quartz grains projecting into the galena (*Ga*) are clearly shown. The illustration also exhibits the xenomorphic texture of the quartz in the quartz-galena bands as well as the rather feeble development of a quartz crust at the quartz-siderite contact. This crust is not always present between the quartz-galena band and the siderite.  $\times = 22.3$ .

structure projecting into and supporting the siderite, and (2) the development of an irregular and discontinuous comb quartz structure which projects into the galena blebs, Fig. 6.

A careful examination of the specimen does not show that a reopening occurred along any of the veins, especially those having non-symmetrical banding. In addition, a reopening and subsequent filling would fail to explain the present banding. If, for instance, the quartz-galena band were due to reopening, then, there should be a band of comb quartz adjacent to the quartz-galena band. On the other hand, a quartz-galena band is absent if the comb quartz band were due to a subsequent deposition in a later fracture. Moreover, comb quartz in a fissure-vein, filled by deposition from homogeneous solutions, should develop from both walls instead of from only the one. The constant occurrence of the quartz-galena band along a very irregular disconnected and branching arrangement of veins, Fig. 2, and always along the lower side of the vein is also inconsistent with a reopening and later filling as the cause of the non-symmetrical banding.

In the laboratory one may produce banding from a saturated aqueous solution by initiating the crystallization of compounds by reducing the

temperature of the solution. If a saturated solution flows through a temperature-controlled chamber of deposition, a band will be produced along all of the walls in contact with the solution. If the heat is extracted uniformly from the walls, the bands will be uniform in character and thickness. If heat is extracted faster from one side, the deposition will then be the heaviest on that side. If heat were not extracted from any surface, crystallization would not occur and if heat were added at any place, the earlier crystals would possibly dissolve depending, however, on the nature of the existing crust and the character of the solution. In any case the direction of growth of the crystals would be toward the solution and away from the support of the bands, or in the opposite direction to the flow of heat.

Under the geological conditions attending the formation of veins it is very improbable that the wall on one side of a vein would be at a sufficiently different degree of temperature and pressure from that of the opposite wall to affect the character of the mineral crusts deposited from a homogeneous solution. If, therefore, the veins under consideration were deposited from a homogeneous solution the quartz bands should both be alike, and not so divergently opposite in character both texturally and mineralogically. One is therefore more or less forced to reject homogeneous solutions, either dilute or concentrated, as the source of the material which produced the mineral bands. Colloidal solutions would likewise deposit like bands on the opposite walls.

If one were to attempt to explain this unique banding on the basis of the replacement of previous mineral bands by later introduced minerals he would have the following relationships and phenomena to explain depending on the assumptions made concerning the initial conditions or starting phase:

1. Why did the replacing solutions attack one band preferentially to another of the same material?
2. Was the comb-quartz band or the quartz-galena band the earlier and why?
3. If the comb quartz is later, why are the grains oriented perpendicularly to the wall, as in a normal comb-quartz crust?
4. Why was the comb quartz or quartz-galena band (depending on the assumptions made) replaced instead of the siderite band when siderite is much more soluble than quartz?
5. Why are the blebs of galena moulded onto quartz grains which are normal to the contact between the quartz and the galena?
6. Why is there a partial, microscopic band of comb quartz between the quartz-galena band and the siderite?
7. If the quartz and galena did not crystallize essentially contemporaneously to produce the quartz-galena band, then which was earlier?
8. If galena is earlier, then why are the quartz grains, that are in contact with the

galena, larger and perpendicular to the contact with the galena while the rest of the quartz is of an equidimensional and fine-grained character?

9. If the galena is later, then the galena either filled vugs in the quartz or replaced residua of an earlier mineral surrounded by quartz, or selectively replaced the fine-grained quartz which was surrounded by relatively large quartz grains. Certain of these inquiries require an explanation if one attempts to account for the structure as a development resulting from selective replacement.

The writer has not been able to evolve a logical sequence of events to account for the structural, textural, and mineralogical relationships on the basis of replacement and has, therefore, discarded this theory as being inadequate to account for the asymmetrically banded veins.

In removing the specimen from the vein without marking its orientation, a very important datum has been lost and that is the vertical position of the specimen in the vein. The illustrations are oriented with the quartz-galena band at the bottom. If the specimen had been oriented otherwise than illustrated, within reasonable limits, the physico-chemical processes influenced by gravity will have been over-emphasized in the writer's tentative theory of origin for these veins. It is hoped that in the future the same or similar veins may become available to geologists and that special effort may be exerted to obtain all data vitally necessary in the solution of this geological riddle.

#### ORIGIN OF THE ASYMMETRICALLY BANDED VEINS

One may readily explain the origin of these non-symmetrical veins on the basis of the known properties of immiscible concentrated solutions. Liquids of this character are well known to metallurgists in the separation of slags and sulphide matts. In the process of separating metals, immiscible liquids consisting of certain compounds of the metals are sometimes used. It is not at all improbable that analogous processes occur in nature.

As the properties of immiscible solution pairs may so readily explain the features of these veins, the writer tentatively proposes a theory of origin involving crystallization from concentrated immiscible mineral solutions.

The solution pairs, in this instance, are indicated by the vein composition, consisting in one instance principally of quartz-galena and in the other of quartz-siderite. The former had a specific gravity of approximately 4.20 and the latter of 3.20, as obtained by measuring the areas of each principal constituent shown on photomicrographs by means of a planimeter. The principal phases and steps in the process of developing the veins appears to be essentially as follows:



1. The solution probably originated nearby as the result of fractionation of an earlier concentrated mineral solution. There are many possible phases, the earlier solution at a higher temperature may have been completely miscible. Lowering of the temperature of the solution, by being injected into the cooler fissures would be a sufficient change of condition for the mineral solution of correct composition to split into two immiscible pairs.

2. The immiscible solutions probably coursed through the fissures as a heterogeneous mass of globules of one liquid suspended in the other.

3. After coming to rest in the fissures, the heavier quartz-galena solution settled to the bottom of the veins where crystallization of the constituents subsequently occurred.

4. The quartz from the quartz-siderite band crystallized first and earlier than the quartz of the quartz-galena band, otherwise a prominent band of quartz would be projecting from the quartz-galena band into the siderite. The contact between the quartz-galena and quartz-siderite must have been a liquid interface until after most of the quartz of the quartz-siderite had crystallized forming the comb-quartz band. Crystallization rarely occurs at a liquid interface which is important in explaining the contact as it occurs between the siderite and the quartz-galena band, Figs. 5 and 6.

5. Before the siderite crystallized, the quartz of the quartz-galena band crystallized quickly as is indicated by the fine-grained texture of the quartz. If the siderite had solidified first, the small band of comb quartz would not project into the siderite. If the siderite had crystallized before the quartz-galena band the small quartz band would either be absent or point into the quartz-galena band.

6. The siderite was the last to crystallize from the quartz-siderite solution while the galena was the last to crystallize from the quartz-galena solution. Before the galena solidified the quartz remaining in the solution developed the small crusts which centripetally surrounded the residual portions of galena-rich solution and upon which the galena crystallized.

7. In the larger vein, Fig. 3, the siderite became sufficiently super-saturated to crystallize before the quartz had completely crystallized. The bands of the siderite almost completely cut off the liquid phase of the quartz from the solid phase. Complete crystallization of the siderite appears to have occurred at once leaving the residual quartz to fill the center of the vein. The xenomorphic texture of the quartz indicates a crystallization which occurred nearly simultaneously throughout the re-

maining solution. The banding in the large vein, *B*, is an example of rhythmic fractional crystallization.<sup>1</sup>

8. During the period of crystallization the solutions must have been at rest, otherwise the separation of the solutions and recrystallization of the minerals would not have produced such well-defined bands.

The theory of origin outlined above accounts for all phases of the veins observed. Neither homogeneous dilute or concentrated solutions, colloidal solutions, or processes of replacement offer a logical explanation for this unique banding.

Experimental work in economic geology and mineralogy does not appear to have attempted projects of the nature which would supply definite quantitative data of the type required to support or disprove a theory of origin for these veins based on immiscible concentrated solution pairs.

It appears desirable that more research be devoted to the behavior of concentrated mineral solutions to provide data that may apply to many of the economic mineral veins.

#### ACKNOWLEDGMENTS

The writer wishes to express his appreciation and thanks to Dr. H. Ries, of the Department of Geology, Cornell University, for suggesting the problem of banding in filled-fissure veins and for making available for study the many specimens of banded veins in the economic geology collection.

<sup>1</sup> Shaub, B. M., The cause of banding in fissure veins: *Am. Mineral.*, **19**, 398-399 (1934)

## NOTES AND NEWS

### NOTE ON THE OCCURRENCE OF CALCIUM SULPHATE HEMIHYDRATE ( $\text{CaSO}_4 \cdot 1/2 \text{H}_2\text{O}$ ) IN THIN SECTIONS OF ROCKS\*

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The partial dehydration of gypsum to the hemihydrate with the loss of one and a half of the two water molecules of gypsum has been studied by many investigators, a recent and definitive paper being that by E. Posnjak.<sup>1</sup> As the transformation of the gypsum to the hemihydrate, and the hydration of the latter back to gypsum, is what occurs in the manufacture and use of plaster-of-Paris, the subject is of great practical importance, and the hemihydrate itself, plaster-of-Paris, is a commodity produced and used in enormous quantities. Also as gypsum and anhydrite are among the commonest of minerals, and since the artificial intermediate hemihydrate is an easily prepared every day article of commerce, it would seem reasonable to suppose that naturally-occurring hemihydrate should be listed as a known mineral. This would seem even more likely, when the well-known partial dehydration of gypsum on simple grinding, or on gentle warming, is recalled. Yet, the hemihydrate is not mentioned in the standard reference works of Dana-Ford, Winchell, or Larsen-Berman.

Even texts specifically dealing with sedimentary petrography, as the recent (1938) third edition of *The Petrology of the Sedimentary Rocks* by Hatch, Rastall and Black, or the *Manual of Sedimentary Petrography* by Krumbein and Pettijohn (1938), do not mention the hemihydrate. Neither does Milner, *Sedimentary Petrography*, though under gypsum he mentions the alteration of anhydrite to a substance "of higher specific gravity than normal gypsum, also a higher refractive index than Canada balsam," and under anhydrite, the change of the latter to gypsum; but it is not clear from the context whether these remarks refer to changes occurring in nature, or to changes occurring in preparing the material for study.

The explanation for the paucity of references to the hemihydrate in mineralogical literature is, of course, that on wetting, the hemihydrate is transformed to gypsum. In other words, it can neither survive wetting, nor crystallize from aqueous solution, under ordinary natural temperatures and pressures. As to its formation from gypsum by drying, this can only take place when the atmosphere is drier than the very low dissociation pressure of the hemihydrate.

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<sup>1</sup> The System  $\text{CaSO}_4\text{--H}_2\text{O}$ , *Am. Jour. Sci.*, 5 ser., **35A**, 247-272 (1938).

tion pressure of gypsum; apparently such a condition of desiccation is nowhere attained on the earth's surface.

The reason for calling attention to these well-known matters is that under certain conditions the hemihydrate is very likely to be encountered in petrographic and mineralogical investigations, and since the usual mineralogical reference texts fail to mention it, some difficulty may be experienced at first in identifying the substance. The heating used to prepare thin sections of gypsiferous rocks, for example, may easily transform platy selenite into fibrous masses of hemihydrate of distinctive optical character, as shown in Fig. 1.



FIG. 1. Apparently a veinlet of a fibrous mineral in a phosphatic shale; actually, hemihydrate developed from selenite.  $\times 30$ . Crossed nicols.

The hemihydrate is characterized by a fibrous or prismatic habit, with indices of refraction  $\alpha = 1.55 \pm$ ,  $\gamma = 1.57$ , birefringence  $= 0.02$ , parallel extinction and positive elongation. The birefringence therefore exceeds that of gypsum, but is less than that of anhydrite; the higher indices distinguish hemihydrate from gypsum, and the lower birefringence, from anhydrite.



## OCCURRENCE OF PINK ZOISITE (THULITE) IN THE UNITED STATES\*

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## ABSTRACT

Pink zoisite (thulite) is known from 12 States with several occurrences in each of five States. The average indices of refraction are:  $\alpha=1.695$ ,  $\beta=1.698$ ,  $\gamma=1.706$ .

## INTRODUCTION

In two papers, Northrop<sup>1</sup> recently has listed four localities in the United States for thulite, the pink variety of zoisite, namely: in Maryland, Connecticut, New Mexico, and North Carolina. The Geological Survey, United States Department of the Interior, has information of several additional localities and these are here placed on record to make available a fuller list of localities of this attractive mineral.

Thulite is known to occur in 12 States, with several localities in each of California, Nevada, North Carolina, Pennsylvania, and Washington. The determined indices of refraction of thulite from a number of the localities listed are given at the end of the paper.

## LOCALITIES

*California*

Numerous boulders of a silicate rock containing pink thulite occur near the south end, on the east side of Saline Valley, Inyo County.<sup>2</sup> A thin section of a specimen, kindly furnished by Dr. Joseph Murdoch, shows much thulite with abundant euhedral crystals of sphene and some epidote.

Bright pink crystals ( $\alpha=1.688$ ,  $\gamma=1.698$ ) in pegmatites at Crestmore (*Am. Mineral.*, **26**, 375 (1941)).

*Connecticut*

At Haddam, in Middlesex County, on the top of Walkley Hill, across the Connecticut River from the famous Gillette quarry, thulite occurs as a band nearly a foot thick in the Middletown gneiss close to its contact with the Haddam tonalite gneiss. Associated minerals are epidote, labra-

\* Published by permission of the Director, Geological Survey.

<sup>1</sup> Northrop, S. A., Thulite in New Mexico: *Am. Mineral.*, **20**, 805-807 (1935); Analyses of thulite, *ibid.*, **21**, 73 (1936).

<sup>2</sup> Pabst, Adolf, Minerals of California: *Division of Mines, Bull.* **113**, 297 (1938). First described as bustamite by Murdoch, Joseph, and Webb, R. W., Bustamite from Inyo County, California: *Am. Mineral.*, **21**, 69-70 (1936).

dorite, and quartz. The occurrence was described by Foye,<sup>3</sup> and is one of the localities cited by Northrop.

### Georgia

The occurrence of thulite at Stone Mountain in De Kalb County, was reported informally by Dr. Alfred C. Hawkins. Dr. Frank A. Daniel of Atlanta, kindly supplied a specimen of pegmatite containing thulite from the Ethel quarry of the Ethel Granite Corporation, situated about two miles northeast of the carving on Stone Mountain.

A thin section shows a few isolated grains of thulite, with very low birefringence, scattered irregularly through the plagioclase feldspar.

### Idaho

Thulite was listed from the Seven Devils district, Adams County, by Shannon,<sup>4</sup> who states that the feldspars of the altered granite, notably at the Arkansaw and Helena mines, have a decidedly pinkish tinge due to the development of thulite. R. S. Cannon of the Federal Geological Survey, has furnished a number of specimens from the Helena mine, which show the thulite filling small veins and occurring as scattered small masses in altered diorite.

### Maryland

Specimens of thulite were obtained from a pegmatite dike in a quarry of hornblende schist formerly operated by Alphaeus H. Wright on Stony Run at Hampton, Baltimore, in 1895.<sup>5</sup> This occurrence was listed by Northrop and is described by Ostrander and Price<sup>6</sup> as the Wright quarry. The bright pink thulite, with gray zoisite shading off into light and dark green epidote, occurred in cracks and veins in oligoclase.

### Montana

Massive, fine-grained pink thulite occurs disseminated through a highly metamorphosed epidotized carbonate rock in the Philipsburg district. Specimens were collected by E. N. Goddard of the Federal Geological Survey in 1939.

<sup>3</sup> Foye, W. G., The occurrence of thulite at Haddam, Connecticut: *Am. Mineral.*, **11**, 210-213 (1926).

<sup>4</sup> Shannon, E. V., The minerals of Idaho: *U. S. Nat. Museum, Bull.* **131**, 322-323 (1926).

<sup>5</sup> Lee, J. W., Occurrence of zoisite and thulite near Baltimore: *Am. Jour. Sci.*, 4th ser., **11**, 170-171 (1901).

<sup>6</sup> Ostrander, C. W., and Price, W. E., Jr., Minerals of Maryland: published by *The Natural History Society of Maryland*, p. 14 (1940).

### *New Mexico*

Thulite from New Mexico was described by Northrop from just south of Pilar Post Office (village formerly known as Cieneguilla), Taos County, on the east bank of the Rio Grande. The occurrence is about three miles northwest of the Harding mine at which there is abundant purple muscovite and close to the occurrence of the deeper colored muscovite from about a mile or so southwest of Pilar (Cieneguilla), described by Schaller and Henderson.<sup>7</sup> Northrop describes the thulite as occurring in a quartz vein traversing schist and in places the thulite has penetrated and apparently replaced the schist. Actinolite is a rare associate. The percentage of manganese (as  $\text{MnO}_2$ ) in the thulite is given as 1.62.

### *Nevada*

Three localities of thulite, all in metamorphosed limestones or dolomites, are described by Gianella,<sup>8</sup> namely:

The southern part of the Pine Nut Mountains, Douglas County. The reference  $118^{\circ}25'$  west longitude given on page 5 of Gianella's paper, apparently is a misprint for  $119^{\circ}25'$ .

Singatse Range, about 11 miles NNE of the first locality, Lyon County.

Ryan Canyon, about 5 miles SE of Thorne, Mineral County.

According to a personal communication from T. B. Nolan of the Federal Geological Survey, thulite also occurs at Eureka, Eureka County, in the Rogers tunnel, 1,150 feet S.  $80^{\circ}$  E. from United States Mineral monument No. 1, Ruby Hill. Specimens collected by Mr. Nolan are very deep pink or red and much deeper colored than most thulite. The indices of refraction are the lowest of those measured, which may be ascribed to the absence of iron, thus accentuating the red color caused by manganese.

### *North Carolina*

Thulite is developed at a number of localities in North Carolina.

The mineral occurs at numerous localities in the Spruce Pine region, and W. J. Alexander of Spruce Pine, and Bradley Johnson of Penland, have kindly furnished the following list of occurrences to which are added two localities at which thulite was collected by Miss Glass in 1936.

#### MITCHELL COUNTY—

Smith mine, within the corporate limits of Spruce Pine, on the hillside just above the Spruce Pine-Bakersville highway, about  $\frac{3}{4}$  mile from the railroad station at Spruce Pine.

Pine Mountain mine on Pine Mountain, 3 miles northwest of Spruce Pine. Leave highway 19 at Minpro. One mile off the highway.

<sup>7</sup> Schaller, W. T., and Henderson, E. P., Purple muscovite from New Mexico: *Am. Mineral.*, **11**, 5-16 (1926).

<sup>8</sup> Gianella, V. P., Thulite in Nevada: *The Mineralogist* (Oregon), **4**, No. 12, 5-6 (1936).



Davis mine, 2 miles from highway 19 on top of Emily Knob, 4 miles northwest of Spruce Pine.

Putnam mine, 5 miles northwest of Spruce Pine, on highway 19, just above the highway where the Penland road intersects it. In this mine and in the Deer Flat mine, granular masses of coarse thulite several centimeters thick lie in oligoclase.

Deer Flat mine, near Penland.

DP2 and DP5 mines, near Penland.

Chestnut Flat mine, 3 miles northeast of Penland.

Flat Rock mine, as slender rose-red crystals in the feldspars.<sup>9</sup>

Press Buchanan mine, 1 mile from Hawk.

Hawk mine, 1 mile north of Hawk Post Office. Some of the oligoclase is colored pink by finely disseminated thulite.

Young mine, at Young Cove, 5 miles north of Bakersville. This thulite has slightly higher indices of refraction than most thulites, almost identical with those of one sample from Pend Orielle County, Washington.

Cloudland mine, at Green Cove, 6 miles north of Bakersville.

#### YANCY COUNTY—

Fanny Gooch mine, 8 miles west of Spruce Pine. Turn south off highway 69 at Newdale, in what is known as the Blue Rock section.

Spider mine, on the Blue Rock road, same vicinity as the Fanny Gooch mine. Fine-grained, massive, and aggregates of coarse prisms in quartz and feldspar.

No. 12 mine, H. Bailey property, just across the North Toe River from the DP2 and DP5 mines.

Northrop lists an analysis with 0.23 per cent of MnO, of a "rose-red zoisite" from the James's mica mine.

On several specimens from the Spruce Pine area, exact mine not known, thulite fills minute fractures in the oligoclase and between plates of muscovite. It also forms radiating groups, at least 4 centimeters long, of prismatic crystals, as masses of coarse prisms, and as fine-grained compact masses, frequently mixed with gray zoisite.

#### MACON COUNTY—

Small grains of thulite were found in 1936 by C. S. Ross and W. T. Schaller at Corundum Hill, near Franklin. The thulite occurs as pink prismatic aggregates in small lenses in altered oligoclase.

#### *Pennsylvania*

Thulite is recorded by Gordon<sup>10</sup> from Deshong's (Leshong's?) quarry, Leiperville (rose red to pale pink, with grossularite), and from Avondale, both in Delaware County. In two old analyses of thulite from Deshong's quarry, MnO is given as 0.43 per cent and as a trace. A "tiny patch" of pink zoisite was found by Wherry<sup>11</sup> in one of the albitite quarries in West Nottingham Township, Chester County, 2 miles northwest of Sylmar.

<sup>9</sup> Genth, F. A., The minerals of North Carolina: *U. S. Geol. Survey, Bull.* **74**, 51 (1891).

<sup>10</sup> Gordon, S. G., The Mineralogy of Pennsylvania: *Acad. Nat. Sciences of Philadelphia, Special Publ. No. 1*, 93 (1922).

<sup>11</sup> Wherry, E. T., Some minerals from Sylmar, Pennsylvania: *Am. Mineral.*, **3**, 47 (1918).



*Virginia*

Very attractive specimens of thulite are found in the pegmatite of the Wheatly mine, close to Moneta, Bedford County. One specimen, collected by W. T. Schaller, shows prismatic crystals, half a centimeter thick and several centimeters long, as well as much fine-grained massive material of a beautiful pink color. A thin section shows abundant thulite developed along the twinning lamellae of plagioclase feldspar with larger areas of almost pure material.

*Washington*

Massive thulite from Okanogan County has been known for some time.<sup>12</sup> The thulite rock is composed of a mixture of grains and prismatic crystals of thulite, plagioclase feldspar and a colorless pyroxene.

Near Metaline Falls, Pend Oreille County, in the northeastern part of the State, it was found in a pegmatitic mass of andesine feldspar and dark green chlorite near the peak on Timber Mountain. The thulite grades through pink epidote into straw colored epidote, in crystals as much as half a centimeter long. Thulite also occurs as fine-grained small spots and knife-edge seams in the muscovite phase of the Kaniksu batholith, in the west center of Sec. 29, T. 36 N., R. 43 E., in the south center of Sec. 32, T. 36 N., R. 43 E., and on the 3,500-foot contour on east slope of ridge in Sec. 35, T. 36 N., R. 43 E. The information on the occurrences in Pend Oreille County was taken by permission of the authors from the manuscript of the unpublished report "The Metaline quadrangle, Washington," by C. F. Park, Jr. and R. S. Cannon.

The thulites from Pend Oreille County have slightly higher indices of refraction with a greater birefringence than most thulites and apparently contain more  $\text{Fe}_2\text{O}_3$ , the pink thulite, grading off into green epidote.

## GEOLOGIC OCCURRENCES

Thulite occurs in the United States in:

Highly silicated contact-metamorphosed limestones and dolomites (Montana, Nevada, Washington?).

Altered granitic rocks and gneisses (Connecticut, Idaho, Washington).

In pegmatites (Georgia, Maryland, North Carolina, Pennsylvania, and Virginia).

In quartz veins (pegmatite?) and surrounding schist (New Mexico).

Its sporadic occurrences in pegmatites lie in a belt extending from

<sup>12</sup> Schaller, W. T., Gems and precious stones in 1915: *Mineral Resources, U. S., 1915*, part 2, 856 (1916).

Delaware County, Pennsylvania, through Maryland, Virginia, North Carolina, to Stone Mountain in Georgia.

The attractive pink to rose-red color is probably caused by small quantities of manganic manganese, with insufficient quantities of ferric iron to neutralize the red color. The quantity of manganese present, judging by the few analyses available, is less than one per cent and usually less than half a per cent. The thulite from Pend Oreille County, Washington, and from the Young mine, Mitchell County, North Carolina, with slightly higher indices of refraction and higher birefringence, probably contain a little more  $\text{Fe}_2\text{O}_3$ .

### OPTICAL PROPERTIES

The indices of refraction of a number of samples were measured by Miss Glass with the following results. Many of the samples show the usual abnormal interference colors of zoisite and where observable, the pleochroism was consistently: X=pale pink or rose, Y=nearly colorless, and Z=pale yellowish. All the samples are optically positive with 2V variable, usually moderate, from about  $30^\circ$  to about  $60^\circ$ . Dispersion  $r > v$ . Usually parallel extinction, occasionally extinguishing at very small angles and possibly grading into pink clinozoisite. The measured indices of refraction are as follows:

MEASURED INDICES OF REFRACTION OF PINK ZOISITE (THULITE)

Locality	$\alpha$	$\beta$	$\gamma$	$\gamma - \alpha$
California	1.690	1.693	1.700	.010
Montana	1.697	1.699	1.705	.008
Nevada, Eureka	1.685	1.688	1.700	.015
North Carolina, Hawk mine	1.690	1.691	1.699	.009
Putnam mine	1.690	1.692	1.698	.008
Deer Flat mine	1.690	1.692	1.699	.009
Chestnut Flat mine	1.695	1.698	1.704	.009
Corundum Hill mine	1.698	1.700	1.705	.007
Young mine	1.704	1.707	1.713	.009
Virginia, Moneta	1.691	1.695	1.702	.011
Washington, Okanogon County	1.690	1.692	1.699	.009
Pend Oreille County	1.705	1.707	1.712	.007
Pend Oreille County	1.705	1.710	1.719	.014
Pend Oreille County	1.703	1.705	1.725	.022

The average of the measured indices of refraction are:  $\alpha = 1.695$  (limits 1.685–1.705)  $\beta = 1.698$  (limits 1.688–1.710),  $\gamma = 1.706$  (limits 1.698–1.725).